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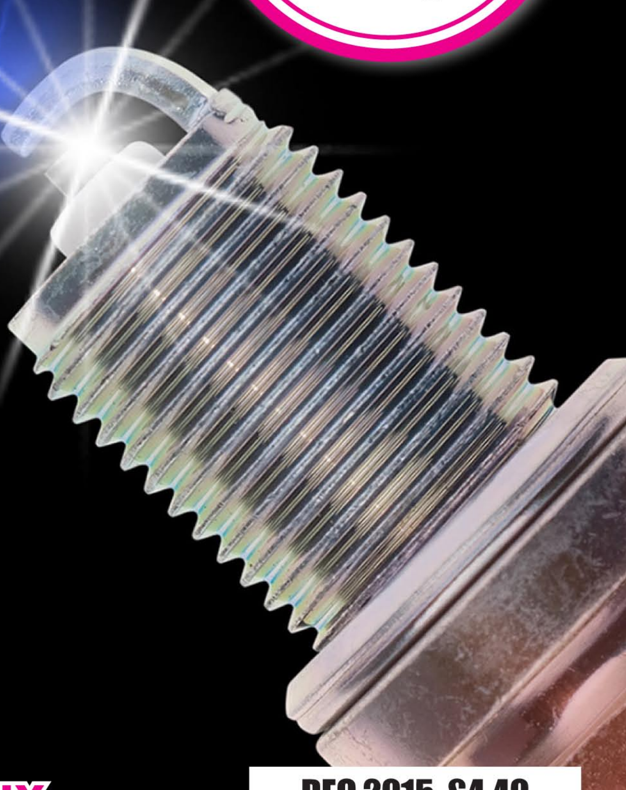

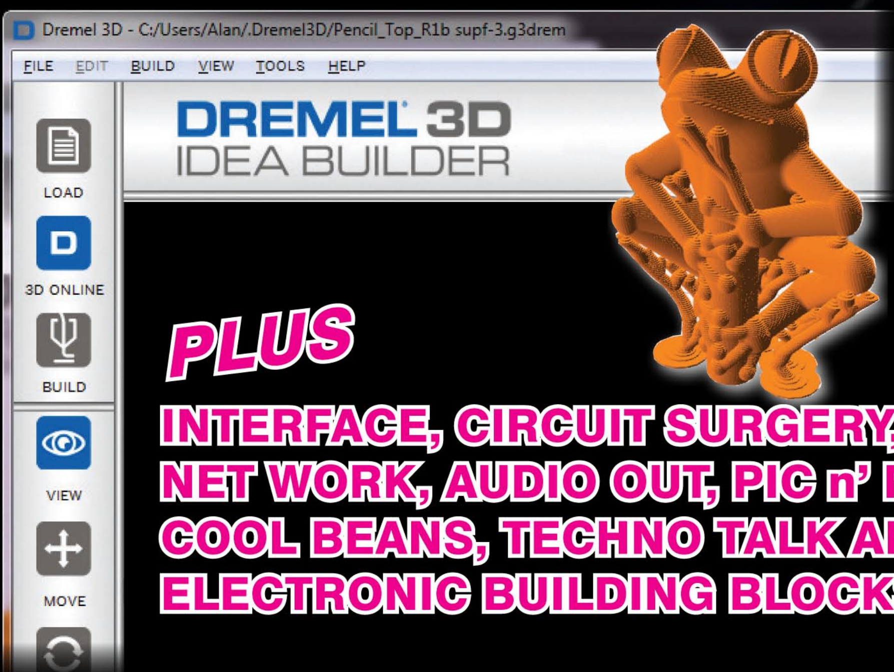

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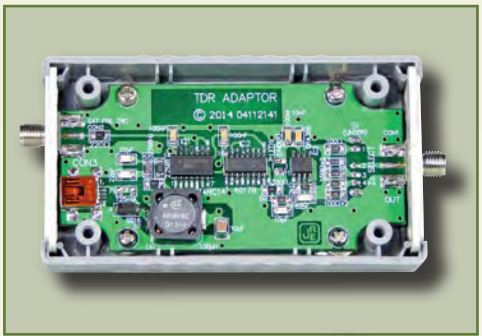

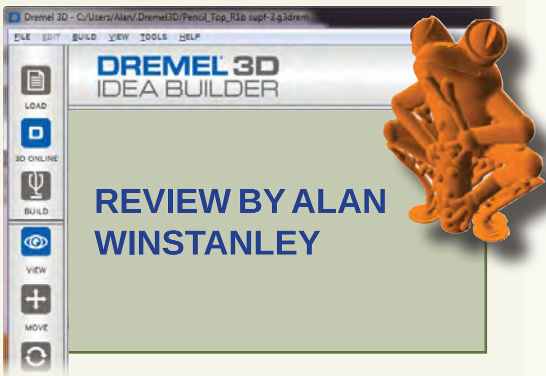

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Our January 2016 issue will be published on Thursday 3 December 2015, see page 80 for details.

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General Manager:	FAY KEARN
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EPE EVERYDAY PRACTICAL ELECTRONICS

Farewell to 2015...

It's been a good year for *EPE* – an excellent ten-part *Teach-In* series took us 'back to basics' with Mike and Richard Tooley's fascinating articles on *Discrete Linear Circuit Design*. Our regular columnists have covered a myriad of electronic areas, from a PIC-based oscilloscope to *Net Work's* must-read developments in the Internet and home computing by Alan Winstanley. Ian Bell's *Circuit Surgery* is an indispensible source of rigorous explanation and Mark Nelson's weird, wonderful and thought-provoking *Techno Talk* reports from the frontiers of technology and science never cease to fascinate.

We said a reluctant farewell to *PIC n' Mix's* Mike Hibbett, but true to form as a stalwart supporter of *EPE* he managed to come up with an excellent replacement columnist – Mike O'Keeffe.

Clive 'Max' Maxfield's *Cool* (and now *Hot*) *Beans* irreverent look at electronics has been fun and informative, and Robert Penfold's *Interface* and *Practically Speaking* articles are, as ever, a vital source of information for those new to electronics. Last, but not least, Jake Rothman's *Audio Out* articles provide the kind of 'hands on' real-world information that you simply cannot find anywhere else.

So, a big 'thank you' to all our regular contributors – without you, *EPE* would not be even half the magazine it is.

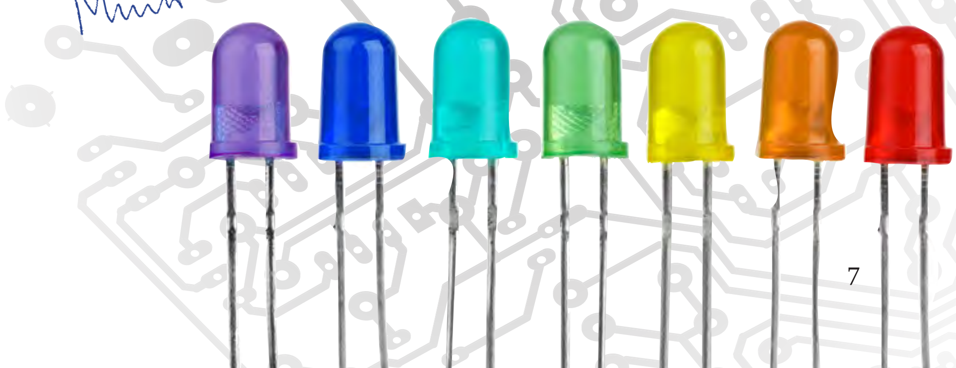
And, I haven't even mentioned last year's project's – too numerous to summarise – but from Hi-Fi and Theremins to Rubidium standards it's been a bumper year. I do hope you found the time and inspiration to build some of them. We are always interested to hear about your successes – and frustrations – so do tell us about anything you have built..

...Looking forward to 2016

So much for 2015, but what's in store for 2016? The Tooley's are already hard at work on next year's *Teach-In* series – I won't spoil the surprise, but it will be devoted to a very popular and easy-to-use microcontroller that can provide simple and creative intelligence to a whole host of projects. It will be fun, useful and a great read.

Looking at the upcoming projects list, I can see something for everyone – Nixie tubes; spark plug energy meters; weather monitors; distortion analysers and… lots more.

I do hope you will enjoy the bumper issues we have coming up in the next 12 months as much as we will enjoy putting them together. If you are ever lost for ideas when the inevitable 'What would you like for Christmas?' question comes your way, then why not suggest a subscription to your favourite magazine – whether you choose paper or online, you can be sure that you won't miss a thing!



NEWS

A roundup of the latest Everyday News from the world of electronics

Underwhelming start for Windows 10 – *report by Barry Fox*

'Windows 10 Lights Up New Devices' promised the advance publicity for a keynote speech at this year's IFA Electronics show in Berlin, held at the beginning of September.

Usually, the prestige of a keynote speech is hitched to a product launch or large stand at the exhibition. But Microsoft had no stand for Windows 10, just a pitch for embedding Microsoft Windows CE 5.0 in hardware by local company Microsoft Deutschland GmbH.

No-questions keynote

For the keynote, Nick Parker, Microsoft Corporate Vice President, spoke of the 'breadth of new Windows 10 devices including tablets, 2-in-1s, premium notebooks, gaming devices and all-in-ones'. Then he quickly disappeared and offered no chance to ask questions. This surprised some of the journalists and bloggers who had attended. I did not attend and was not surprised. Microsoft managers now seldom come down from their mountain to do more than deliver a speech and then quickly retreat to the safety of silence.

Millions of testers...

The IFA keynote followed soon after the launch of Windows 10, with free updates for all because Windows 8 has proved so unpopular (largely because it was so uncomfortably different from all previous versions of Windows) that it was actively deterring people from replacing old PCs – including those running obsolete hardware under obsolete Windows XP, or ageing hardware under popular but discontinued Windows 7. Microsoft claims to have Beta-tested Windows 10 with 'millions of users' before the official launch.

Despite this testing and although Windows 10 is marginally nicer to use than Windows 8 – and can be set to look and feel more like Windows 7 – it is beset with practical problems.

Clumsy installation

Upgrading from Windows 8 is free but not easy. Inexplicably, the upgrade path can only be from Windows 8.1, not 8.0. The upgrade from 8.0 to 8.1 must be done first and involves a time-consuming download and installation process. The upgrade from 8.1 to 10 involves another large download and another time-consuming install.

The install may fail for no apparent reason, with the monumentally unhelpful error message 'Something happened – Close'. Internet searches confirm that many have had this same problem.

Asked to comment, a Microsoft spokesman responded 'Thanks for letting us know.'

A Microsoft insider, speaking off the record, admitted that he had found 'the easiest way to upgrade to Win 10 was to totally ignore the automatic update and initiate the process by using the media creation tool. The 32- and 64-bit versions are available here: **http://windows.microsoft.com/en-gb/windows-10/media-creation-tool-install** – it lets you also have the option to create a decent set of installation disks or a USB drive with tools that let you exert a degree of control over the process.'

The clear message is that any new PC should be bought with Windows 10 already installed. Older stock, which may still come with Windows 8 and the promise of a free upgrade to Windows 10, should be avoided like the plague.

Software incompatibility

Be aware too that some software that worked under Windows 7 and 8, may no longer work under 10. Also, some familiar features of Windows have been changed for the worse.

For example, AOL has had to release a new version (Ver 9.8) of its desktop email client because the previous version (9.7) crashed when sending email with Windows 10. Before the new version was ready AOL was describing a risky process for digging deep inside the AOL software on a PC, and replacing a file called **htmlview.tol** with a new version downloaded from AOL.

The powerful and intuitive search function built into previous versions of Windows, which lets the user hunt through all documents on the PC for a string of text, has been changed with Windows 10. Microsoft's search system, called Cortana, now by default uses Bing (Microsoft's answer to Google) to scour the Internet as well as the PC – unless actively prevented from doing so by a tricky routine for disabling Cortana and Bing.

Startisback alternative

Be aware that an alternative to upgrading from Window 8 to 10 is to install the excellent software Startisback that makes Windows 8 look and feel much more like Windows 7. Startisback also improves the look and feel of Window 10. The program costs only a few dollars and the makers offer a free trial before purchase: **http://startisback.com**

All in all, it's not hard to see why Microsoft's keynote speaker at IFA was taking no questions.

Porsche goes electric

Porsche's all-electric Mission E: 0-60 in 3.5s, 155mph top speed and a range of 300+ miles

Once the butt of endless unflattering 'milk-float' jokes, electric cars are slowly but surely attracting the attention of mainstream and now even high-end German auto manufacturers. A couple of years ago, luxury car manufacturer BMW debuted its i3, a five-door electric car with a 125kW motor, 22kWh lithium ion battery and a claimed range of 130-160km. Now, an icon of the internal combustion engine – Porsche – is moving into the electric vehicle market.

At the Frankfurt Auto Show in September, Porsche revealed its Mission E concept car. Sporting four doors and all the luxury associated with the Porsche brand, Mission E will be the company's first all-electric car.

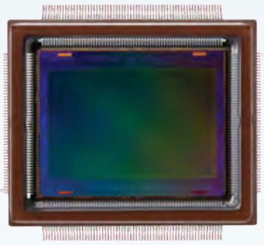
Porsche claims the Mission E's range is well over 300 miles for real-world driving and that its batteries can be recharged to 80% in 15 minutes with their 'Turbo Charging' system. Performance stats are an impressive 0-60mph in under 3.5 seconds and a top-speed of 155mph.

Mission E boasts matrix LED headlights and a holographic display that extends far into the passenger's side. It shows individually selectable apps, which are stacked in virtual space and arranged by priority with a three-dimensional effect. The driver – or passenger – can use these apps for touch-free control of media, navigation, climate control, contacts and vehicle.

For now, Mission E is a concept car, but Porsche claim they expect it to arrive in showrooms within five years.

Canon's 250 megapixel sensor

Canon has developed an APS-H-size (approx. 29.2 × 20.2 mm) CMOS sensor incorporating approximately 250 million pixels (19,580 × 12,600 pixels), the world's highest number of pixels for a CMOS sensor smaller than a 35mm full-frame sensor.



When installed in a camera, the newly developed sensor was able to capture images enabling the distinguishing of lettering on the side of an airplane flying at a distance of approximately 18km from the shooting location.

The new CMOS sensor achieves an ultra-high signal readout speed of 1.25 billion pixels per second, made possible by enhanced signal-processing technology.

Canon is aiming this technology at specialised surveillance and crime prevention tools, ultra-high-resolution measuring instruments and industrial equipment.

Artificial emotions

You've heard of CPUs, ALUs and UARTs, but what about EPUs? AI company EmoSHAPE has created an 'emotion processing unit', which creates a synthesised emotional response in machines. This dedicated chip allows AI technology to experience one of eight human emotions (anger, fear, sadness, disgust, surprise, anticipation, trust and joy), which generate virtual levels of pain, pleasure and frustration and enable it to 'react' in a way that is similar to a human.

The EPU has an 'emotion profile graph' (EPG), which allows AI that uses it to develop a long-term personality. Company CEO Patrick Rosenthal is: '…talking to expert Asian manufacturers who specialise

in robotic pets. Our aim is to integrate our EPU into their technology, which we believe will take its AI to the next level. This technology will essentially allow a robotic pet to create a completely unique personality depending on a number of factors, which will ultimately mean that no two have the exact same personality.'

PET – the squishy transistor

Researchers from the National Physical Laboratory (NPL), IBM, the University of Edinburgh and Auburn University have shown that a new device concept – a 'squishy' transistor – can overcome the predicted power bottleneck caused by CMOS technology reaching its fundamental limits.

Moore's Law predicted that the number of transistors able to fit on a given die area would double every two years. As transistor density doubled, chip size shrank and processing speeds increased. This progress led to rapid advances in information technology and a surge in the number of interconnected devices. The challenge with making anything smaller is that there are fundamental physical limits that can't be ignored and we are now entering the final years of CMOS transistor shrinkage.

Furthermore, this proliferation is driving an increase in data volume, accompanied by rising demands on energy to process, store and communicate it all; as a result, IT infrastructure now draws an estimated 10% of the world's electrical power. Previous efforts have focused on remediation by reducing the amount of energy per bit. However, soon we will hit a power barrier that will prevent continued voltage scaling. The development of novel, low-power devices based on different physical principles is therefore crucial to the continued evolution of IT.

The research team has demonstrated the capabilities of the 'piezoelectric transistor' (PET) as a post-CMOS technology that could overcome these issues and restore voltage scaling. In their paper, published in *Applied Physics Letters*, the team explain the physics underlying the PET's behaviour and use theory and simulation to predict its performance when optimised across a wide range of application spaces, spanning several different length scales: including radio frequency switches (on the micron scale) and devices such a smartphones and phased array radar.

The conceptual device is based on a pressure-driven insulator-to-metal transition, and has proved to be a promising, fast, low-power option for future IT infrastructure, with a performance that cannot be matched by CMOS transistors. These results should spur further research into piezoelectric scaling, and the PET fabrication techniques needed to realise this device in the future.

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TechnoTalk

Mark Nelson

Dirty electricity and power purity

Mains power — we take it for granted. But is all electricity equally good? And is it always benign? Can it upset electronic equipment or even your health? Mark Nelson checks out the buzz.

IF YOU EVER MET GERRY WELLS, the genial curator of the Vintage Wireless Museum in London, you'll know he had a way with words. Although he died earlier this year, I'm sure that some of his witticisms will live on. When he encountered old radios that worked only intermittently, he put the blame on 'dirty electricity'. It was just a joke, but as Google discovered in August when lightning struck four times in succession near to one of its data centres, the purity of power is vital in this digital age.

Google loses data as lightning strikes

That was the headline on the BBC news website, which reported that some clients had permanently lost access to their files as a result. Others, who also used the data centre to store data and run virtual computers in the cloud, were more fortunate and regained access to their information once normal service was restored. The website quoted Justin Gale, an expert on lightning protection, who explained that lightning did not have to strike the actual building to cause damage. In this case, lightning induced power surges into the local power grid (mains supply) and it was this that caused the disruptions. Said Gale, 'The cabling alone can be struck anywhere up to a kilometre away, bring [the shock] back to the data centre and fuse everything that's in it.' Commenting on this event, trade paper *Electronic Engineering Times* remarked that wiping data on hard drives was just an extreme example of the perils of power surges. Less obvious was the reduced working life on electronic devices caused by repeated (but smaller) power surges.

But lightning is not the only pollutant of power mains, and although the consequences are more subtle, they are still real. Switch-mode power supplies can superimpose harmonics on the 50Hz or 60Hz (depending on where you live) power line as a result of their chopper circuits that operate at far higher frequencies. These, states *EETimes*, are responsible for numerous problems, particularly in industrial environments. Harmonics, it explains, can lead to increased energy consumption and noticeable component damage, while voltage ripples or waveform distortion introduced into the mains supply may cause problems that are hard to pin down. Electromagnetic interference (EMI) generated as a result of harmonics may affect telecommunications equipment, metering apparatus and entertainment electronics (radios and Hi-Fi equipment).

Wacky web resources

Not surprisingly, the web is awash with resources to consult if you feel like following up power pollution. Some are commercial, even if this is not immediately obvious (such as **www.dirtyelectricity.org**), while others are campaigning. In this category we have numerous sites railing against what they call 'dirty electricity', which harms people suffering from electrical hypersensitivity. This is undoubtedly a real condition, but to blame problems caused by RF radiation onto dirty electricity (and to sell mains filters or even crystals for mitigating these effects of 'electrosmog') seems either desperately misinformed or downright disingenuous (**www.electricsense.com/9988/emf-protec tion-crystals**). Smart meters are another target of the doomsayers. The site **https://takebackyourpower.net** sells an electrosmog meter that measures the microwave radiation intensity from 'smart' electricity meters, 'which emit 1,000 to 10,000x higher peak radiation than an active cell phone'.

On the same tack **http://stopsmartmeters.org** explains why smart electricity meters are unsafe, which is on account of the 'substantial' emissions from the meter at 915MHz (which is the frequency used in the USA for transmitting meter readings to base station that collect this data). This of course has nothing to do with the mains, but in a confused way the website switches track to assert that: 'Electric wiring – in addition to carrying current – can also act as an antenna, creating what are essentially 'antenna cages' in homes. Pulsed microwaves from the meters, as well as dirty electricity resulting from the conversion from AC to DC current, can create hazardous conditions. When you have dozens or hundreds of smart meters pulsing and emitting dirty power transients in the same wavelength, electrical pollution can be intensified.' Yeah, right.

Are we doomed then?

Possibly, according to the veteran entertainer Noel Edmonds, who in August claimed: 'The biggest problem we have is not Ebola, it's not AIDS; it's electrosmog. We're surrounded by electro-mist, fog and smog. We're covering ourselves in the wrong sorts of electromagnetism. The Wi-Fi and all of the systems that we are introducing into our lives are destroying our own natural electromagnetic fields.'

Fortunately, he has a solution in the form of a special 'yoga mat' that he uses for eight minutes every day. This EMPpad, based on research by NASA, recalibrates your blood cells and readjusts the electromagnetism in your body. 'Think of a yoga mat, connected to a computer; it provides you with pulsed electromagnetism,' he told the *Daily Mirror*. 'It's a brilliant technology. It is not cheap, it costs £2,000. It removes pain and reduces stress, and people tell me I don't look 66.'

That's fantastic. I do hope an *EPE* reader will reverse-engineer one of these miracle gadgets to enable the magazine to sell a clone device at a more wallet-friendly price.

Lethal mud

Getting back to murky mains, greater rationality is found at **www.strayvoltage.org**, which sets out to be a resource for information on the stray currents in the ground that can have lethal consequences. This problem occurs particularly in rural areas, where the return leg of overhead power supplies sometimes takes a short cut back to the generating station via the poles' earthing conductors. If a dairy farm stands in the way, the mud, milking machines and metal water troughs can conduct the current to the cows, with deadly consequences. A $17 million judgment was made against the Idaho Power Company in one stray-voltage case involving dairy cows. In another instance, in south-western Washington state, a dairy farmer won a $1 million verdict against the power utility, and other cases abound.

High-Energy Multi-Spa
for Performance Cars

This capacitor discharge ignition (CDI) system is designed to provide a very high energy multi-spark discharge each time the spark plug is fired. It enables complete mixture combustion in virtually all internal combustion engines used in cars and motorcycles, and is especially effective with engines that run at high RPM.

WHILE FACTORY-SUPPLIED ignition systems in modern vehicles operate reliably and give a high-energy spark, there are many situations where a multi-spark capacitor discharge ignition (CDI) can provide a better result than the standard ignition. Perhaps the best examples are old 4-stroke engines with conventional points ignition and all 2-stroke engines.

The faster rise time, hotter sparks and multiple spark discharges can easily fire plugs that are fouled up with carbon caused by oil in the fuel. Again, with an older engine, a multi-spark CDI system can be especially beneficial when the engine is cold and running with a rich fuel mixture.

A CDI also draws less power from the vehicle's 12V battery compared to conventional ignition systems. This can be a real advantage where a vehicle has a low output alternator or generator, or in some racing vehicles where no alternator is fitted (eg, in drag racing).

One drawback of CDI systems is the potential of cross-fire between spark plugs due to the rapid rise time of the spark voltage. Cross-fire sounds like 'pinging' and can cause severe engine damage if it happens consistently. Therefore, we do not recommend using our *High-Energy Multi-Spark CDI* system on 6-cylinder and V8 engines unless you can improve the lead dress of the spark plug leads so that each lead is more widely separated from its neighbour.

ark CDI

Part 1: By JOHN CLARKE

Features and specifications

Main features

- Suitable for 2-stroke and 4-stroke engines
- Multiple spark output (see Table 1)
- Provides a shorter-duration hotter spark than traditional ignitions
- Operates on relutor, points, optical, engine management or Hall effect signals
- Usable to 1000 sparks/second (equivalent to 15,000 RPM for a V8)
- Regulated 300V supply for consistent spark energy
- High-frequency operation eliminates audible oscillator noise
- Efficient circuitry for minimum heat generation

Specifications

- Spark energy without multi-sparking: 11mJ measured with Bosch GT40 ignition coil, 15mJ with VW Caravelle T4 ignition coil
- Number of sparks per firing: minimum of two (see Table 1)
- Spark separation: 0.5ms for the first two sparks, then 0.66ms, 0.33ms, 0.66ms...
- Spark duration: About 200μs per spark
- Multiple spark period: two sparks = 700μs; four sparks = 1.5ms; six sparks = 2.4ms; eight sparks = 3.3ms; 10 sparks = 4.3ms; 12 sparks = 5.2ms; 14 sparks = 6.2ms
- Reluctor circuit sensitivity: 400mV RMS
- Inverter operating frequency: 60kHz
- Operating voltage: down to 9V
- Current drain at 13.8V with multi-sparking: 200mA @ 0Hz, 1A @ 50Hz, 2A @ 150Hz, 3A @ 400Hz, 4A @ 500Hz
- Delay between trigger and firing: 1μs

If you have an older car, there is no reason why this CDI system should not be a satisfactory substitute, particularly if the original module has failed and is expensive to replace.

Our new CDI system can be triggered by conventional ignition points, Hall effect, optical, engine management or reluctor pick-ups. It's capable of operation to very high engine speeds, much higher than even racing engines reach. For example, it can run as high as 30,000 RPM in a 4-cylinder engine. This figure is so high that it's academic, but it does indicate that full spark energy is maintained over the entire RPM range of any practical engine.

Multiple-spark discharge

So what is 'multi-spark'? Standard transistor-switched and CDI ignition systems produce a single spark each time the mixture in the cylinder is ignited. 'Multi-spark' produces several sparks which are fired in quick succession. Our new design produces up to 10 sparks each time a spark plug is to be fired, depending on the engine speed.

If you wish, this feature can be disabled so that the CDI produces just two sparks for each cylinder firing, regardless of engine speed.

The advantage of multi-sparking is that it ensures a more complete burn of the fuel, especially when firing is prone to be difficult in a cold and rich-running engine.

Fig.1(a) shows the schematic diagram of the conventional Kettering ignition system which has been used in cars since 1910 (originally introduced on the Cadillac). It comprises an ignition coil which has its primary winding connected to the battery supply and a switch in the negative side.

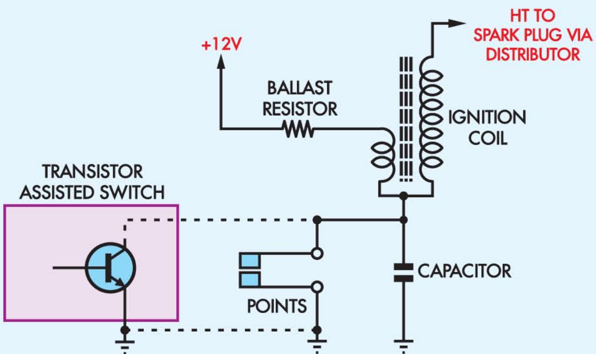


Fig.1(a): the Kettering ignition system uses points or a transistor to interrupt the current through the coil.

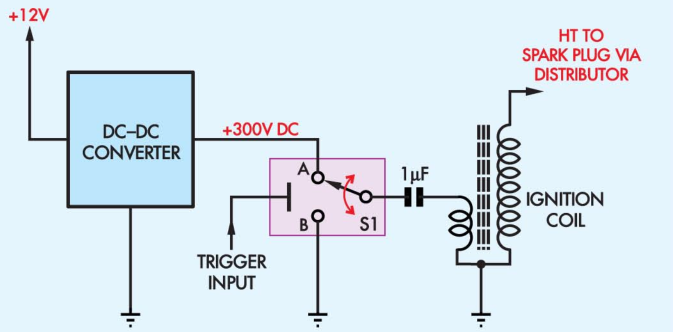


Fig.1(b): the *Multi-Spark CDI* uses a DC-to-DC inverter to charge a 1μF capacitor when S1 is at A. This capacitor then discharges through the coil when S1 switches to B.

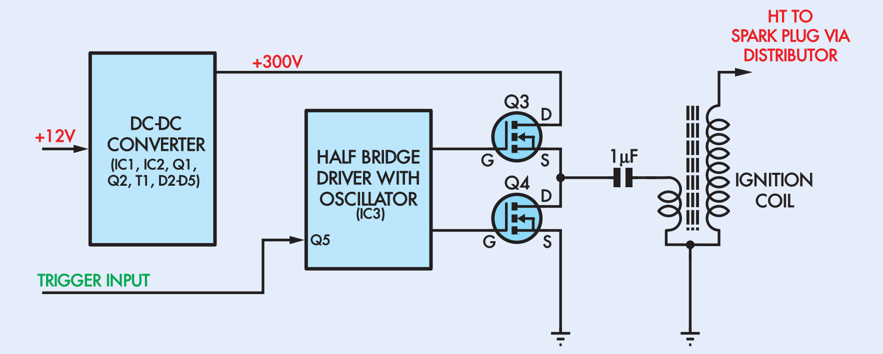


Fig.2: block diagram for the *CDI Multi-Spark Ignition*. The 300V output from the DC-DC converter is fed to the drain of MOSFET Q3 which is used as a switch to direct current flow through a 1µF capacitor. MOSFET Q4 then shunts the lefthand side of the capacitor to ground to fire the coil (after first switching off Q3). When Q4 is switched off and Q3 is switched back on again, another spark is generated as the 300V DC is re-applied to the capacitor.

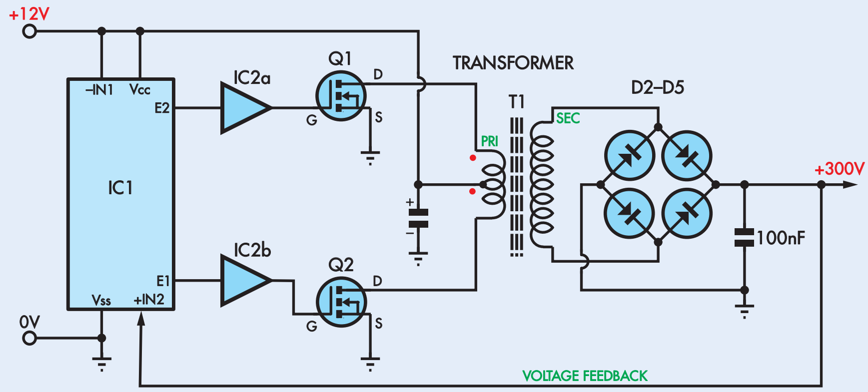


Fig.3: simplified circuit of the DC-DC converter. MOSFETs Q1 and Q2 are driven by a switch-mode PWM waveform generated by IC1 via buffers IC2a and IC2b. The MOSFETs in turn drive the centre-tapped primary winding of transformer T1 and the output from the secondary is fed to a bridge rectifier (D2-D5) and a 100nF filter capacitor to produce the 300V DC output.

The switch can be a conventional set of points or a switching transistor, as used in most modern ignition systems. When the switch is closed, current increases in the primary winding and is only limited by the internal resistance of the coil and a ballast resistor (if used). The maximum current is usually up to 5A.

When the switch opens, the resulting collapse of the magnetic field in the coil causes the secondary winding to produce a high voltage to fire the spark plug. As the engine speed rises, the current has less time to build up in the coil primary and so inevitably the spark energy is reduced. Modern transistor-assisted ignition systems get around this problem by using ‘dwell extension’, lower inductance coils or more than one ignition coil, as in direct-fire ignition systems.

Fig.1(b) shows how a typical CDI system works. It has a DC-to-DC inverter with a regulated 300V DC output which charges up a 1µF capacitor. This capacitor charges up via the coil to 300V when S1 is in position A and discharges through the coil when the switch is in position B. Thus, each time a spark plug is fired, two sparks are produced – one with positive polarity and one with negative polarity. The CDI can be made to produce more than two sparks for each firing by repeatedly charging and discharging the 1µF capacitor.

Note that older CDI design versions have the lefthand side of the capacitor permanently connected to the DC-DC converter output. This side of the capacitor is switched to ground for firing, usually by an SCR. This arrangement means that the DC-DC converter is effectively shorted to ground and needs to shut down on each firing (otherwise the SCR would continue to conduct).

Fig.2 shows the block diagram for CDI ignition. The DC-DC converter’s 300V output connects to the drain of MOSFET Q3 which is used as a switch to direct current flow through the 1µF capacitor. MOSFET Q4 then shunts the left side of the capacitor to ground to fire the coil (Q3 is switched off first). When Q4 is switched off and Q3 switched back on, there is another spark generated as the 300V is reapplied to the capacitor.

DC-DC converter basics

The basic principle of the DC-DC converter is simple. It works by alternately switching the 12V battery supply to each half of a centre-tapped transformer primary winding. The resulting square waveform is stepped up by the transformer’s secondary and then rectified and filtered to provide the 300V DC supply rail.

Fig.3 shows the simplified circuit of the DC-DC converter. The circuit operates at a switching frequency of about 60kHz and uses a high-frequency ferrite transformer. The centre-tapped primary winding of the transformer is driven by MOSFETs Q1 and Q2. Q1 drives the top half of the step-up transformer, while Q2 drives the bottom half. The secondary winding’s output is fed to a bridge rectifier and filter capacitor to produce the 300V DC output rail.

The MOSFETs are driven by a switch-mode PWM (pulse-width modulation) waveform generated by IC1. This feeds complementary (ie, out of phase) gate signals to the MOSFETs via buffers IC2a and IC2b. Negative feedback is applied to the +IN2 input of IC1 from the 300V DC output via a voltage divider (not shown). This feedback circuit acts to reduce the width of the pulses applied to the MOSFETs if the DC voltage rises above 300V.

Conversely, the pulse width from the driver circuit increases if the output voltage falls below 300V. Since the MOSFETs are switched in anti-phase, when one half of the winding is conducting, the other is off.

The DC-DC circuit also incorporates a low-voltage cut-out to protect the battery from over-discharge. It monitors the battery voltage at –IN1 and if it drops below 9V, the DC-DC converter switches off.

Circuit details

Refer now to Fig.4 for the full circuit of the *High-Energy Multi-Spark CDI*. Its DC-DC converter is based on a

Parts List

1 PCB, available from the *EPE PCB Service*, code 05112141, 110.5 × 85mm
1 diecast metal case, 119 × 94 × 57mm
1 ETD29 transformer (T1) consisting of 1 × 13-pin former, 2 × N87 cores (element14 Cat. 1781873) and 2 × clips
1 S14K 275V AC metal-oxide varistor (MOV1)
2 IP68 cable glands, 4-8mm cable diameter
4 M3 × 9mm tapped spacers
4 TO-220 silicone insulation washers
4 insulating bushes
1 100kΩ top-adjust multi-turn trimpot (VR1)
4 M3 × 9mm tapped nylon spacers
5 M3 × 10mm screws
4 M3 × 6mm screws
4 M3 × 6mm countersink-head screws
5 M3 nuts
2 3mm star washers
2 solder lugs
1 20m length of 0.25mm-diameter enamelled copper wire (for T1 secondary)
1 1200mm length of 1.0mm-diameter enamelled copper wire (for T1 primary)
1 2m length of red automotive wire
1 2m length of black automotive wire
1 2m length of green automotive wire
1 2m length of white automotive wire

Semiconductors
1 TL494CD SOIC switch-mode PWM control circuit (IC1)*
1 TC4427COA SOIC high-speed MOSFET driver (IC2)*
1 L6571AD SOIC high-voltage half-bridge driver with oscillator (IC3)*
2 STP60NF06 60V 60A N-channel MOSFETs (Q1,Q2)*
2 FDP10N60NZ 10A 600V N-channel MOSFETs (Q3,Q4)*
2 BC337 NPN transistors (Q5,Q6)
1 16V 1W Zener diode (ZD1)
1 75V 1W Zener diode (ZD2)
1 1N4004 1A 400V diode (D1)
5 UF4007 fast rectifier diodes (D2-D6)
3 1N4148 switching diodes (D7-D9)
* available from element14.com

Capacitors
1 4700µF 16V PC low-ESR electrolytic
3 100µF 16V PC low-ESR electrolytic
1 10µF 16V PC electrolytic
2 1µF 50V monolithic multilayer ceramic (MMC)
1 1µF X2 class 275VAC MKP metallised polypropylene (Vishay BFC233922105*)
2 100nF X2 class 275VAC MKP metallised polypropylene
3 100nF 63/100V MKT
1 4.7nF 63/100V MKT
1 1nF 63/100V MKT
1 C1 (470nF for 8-cylinder, 150nF for 6-cylinder, 120nF for 4-cylinder), 63/100V MKT
* available from element14.com

Resistors (0.25W, 1%)

3 1MΩ	1 13kΩ
2 680kΩ	7 10kΩ
2 270kΩ	1 8.2kΩ
2 180kΩ	2 4.7kΩ
1 56kΩ	1 2.2kΩ
2 47kΩ	2 22Ω
1 33kΩ	3 10Ω
2 33kΩ 1W	

Points version
1 100Ω 5W resistor (R1)

Reluctor version
1 BC337 NPN transistor (Q7)
1 5.1V 1W Zener diode (ZD3)
1 2.2nF MKT polyester capacitor
1 470pF ceramic capacitor
1 100kΩ top adjust multi-turn trimpot (VR2)
1 47kΩ 0.25W 1% resistor
1 10kΩ 0.25W 1% resistor
1 10kΩ 0.25W 1% resistor (R4)
1 1kΩ 0.25W 1% resistor (R3)
2 150Ω 0.25W 1% resistors

Hall Effect/Lumenition Module
1 5.1V 1W zener diode (ZD3)
1 150Ω 0.25W 1% resistor
1 1kΩ 0.25W 1% resistor (R3)
1 100Ω 0.25W 1% resistor (R2)

Optical Pick-up
1 optical pick-up (Piranha or Crane)
1 5.1V 1W zener diode (ZD3)
1 22kΩ 0.25W 1% resistor (R3 or R6)
2 150Ω 0.25W 1% resistors
1 120Ω 0.25W 1% resistor (R4 or R5)

Miscellaneous
Heatshrink tubing, angle brackets for mounting, automotive connectors, self-tapping screws

Texas Instruments TL494 switch-mode driver (ICI).

This device has been available since the early 1980s and is still used today in many switch-mode power supplies. The IC contains all the necessary circuitry to generate complementary square-wave outputs at pins 9 and 10 and these drive the gates of the MOSFETs via MOSFET drivers. The IC also contains control circuitry to provide output voltage regulation and low voltage cut-out.

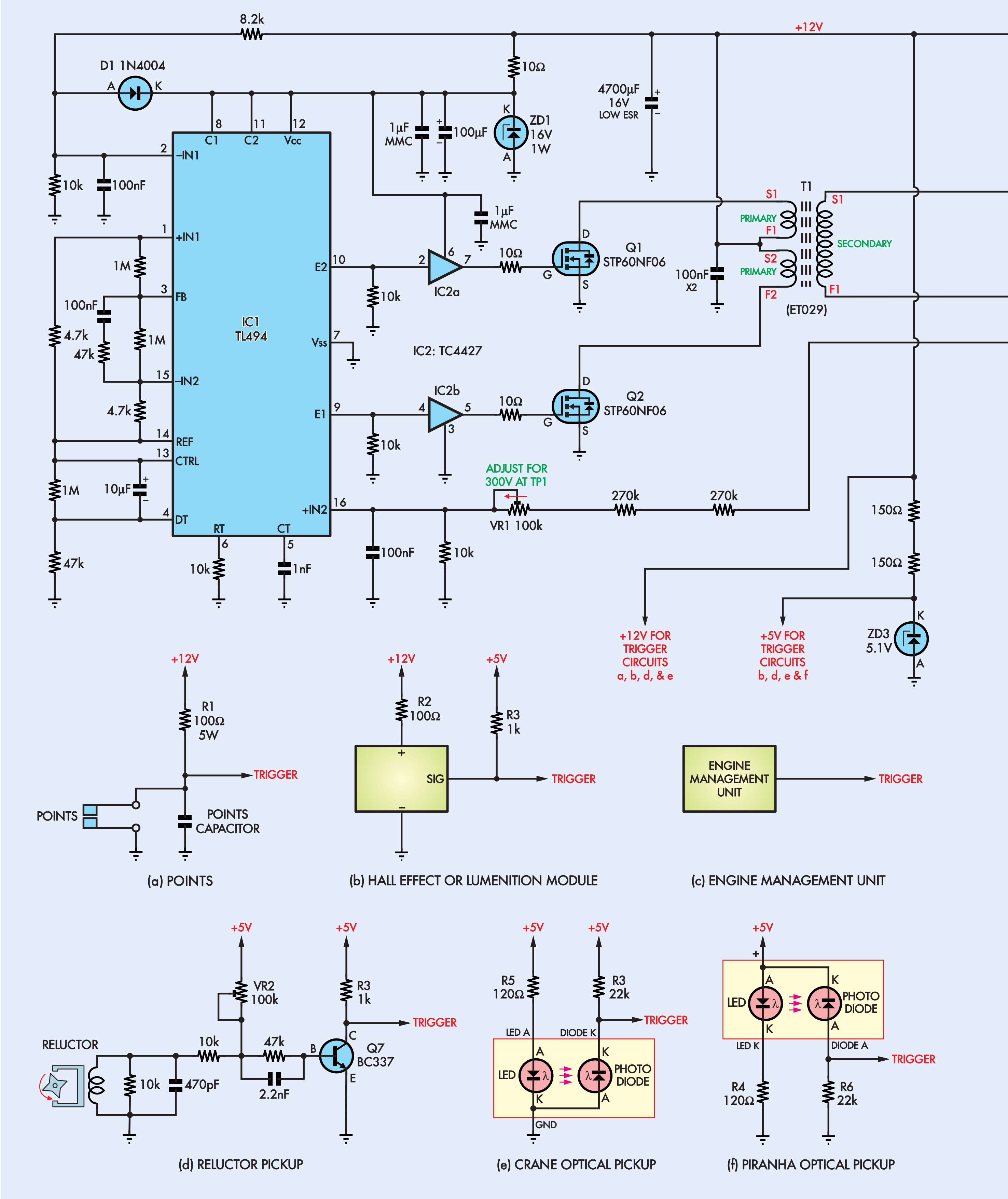
Fig.5 shows the internal circuitry of the TL494. It's a fixed-frequency PWM controller containing a sawtooth oscillator, two error amplifiers and a PWM comparator. It also includes a dead-time control comparator, a 5V reference and output control options for push-pull or single-ended operation.

The PWM comparator generates the variable-width output pulses by comparing the sawtooth oscillator waveform against the combined outputs of the two error amplifiers. The error amplifier with the highest output voltage sets the pulse width.

The control (CTRL) output at pin 13 of IC1 is used to set either single-ended output or push-pull operation. In our design, push-pull (ie, anti-phase) outputs are selected and these are produced at the transistor emitters at pins 9 and 10 (E1 and E2). These internal transistors have their collectors tied to the positive supply rail.

Dead-time comparator

The internal dead-time comparator ensures that there is a brief delay before one output goes high after the other has gone low. This means that the outputs at pins 9 and 10 are both low for a short time at the transition



MULTI-SPARK CAPACITOR DISCHARGE IGNITION

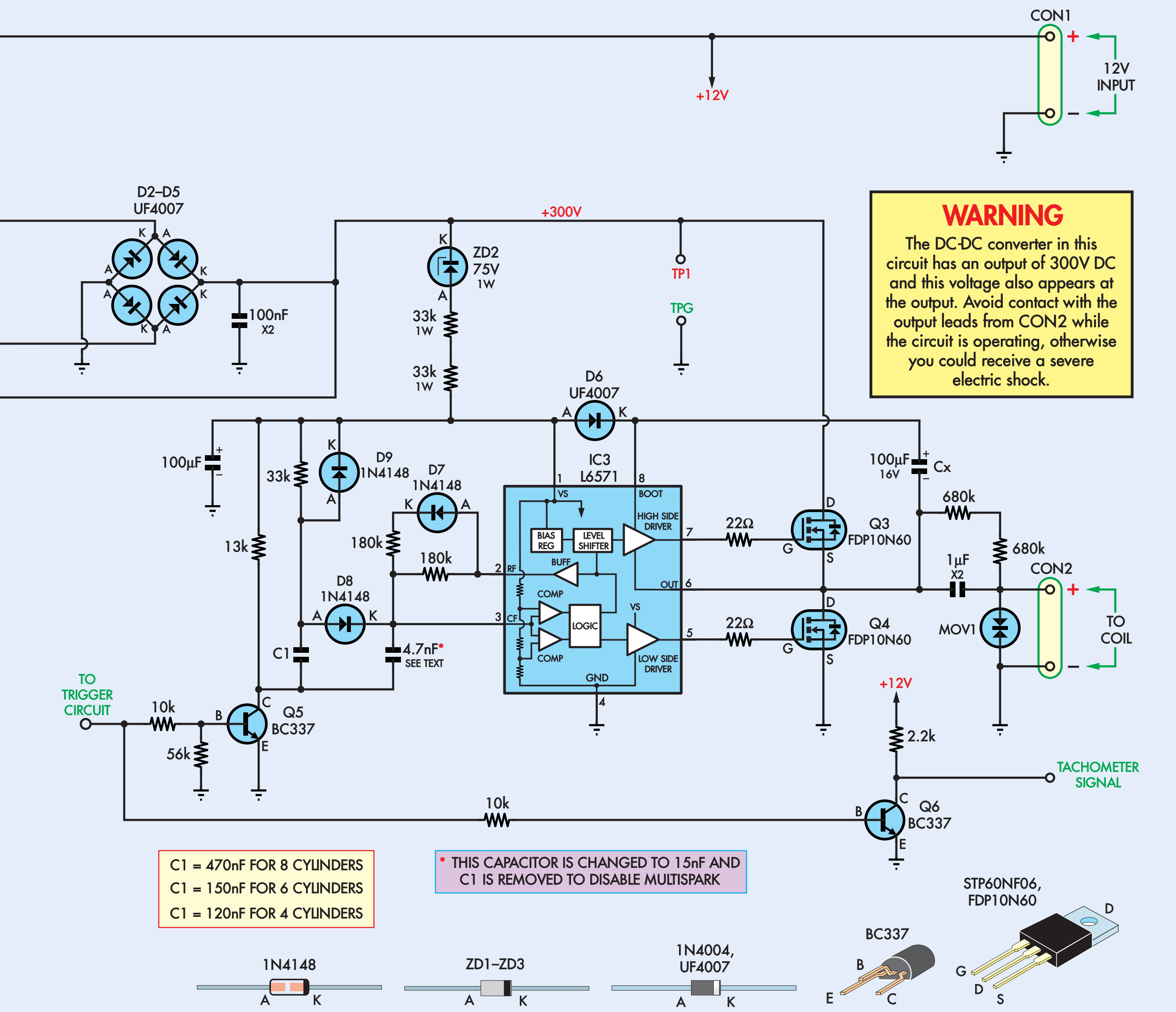


Fig.4: the circuit is based on IC1, which is a TL494 switch-mode driver. This combines with MOSFETs Q1 and Q2, transformer T1 and bridge rectifier D2-D5 to form the DC-DC converter. IC3, an L6571AD high-voltage half-bridge driver and oscillator, is used to alternately switch MOSFETs Q3 and Q4 to charge and discharge the 1µF capacitor via the ignition coil. The circuit caters for six different input triggers: (a) points; (b) Hall effect/Lumenition triggering; (c) engine management module triggering; (d) reluctor pickup; (e) Crane optical pickup; and (f) Piranha optical pickup.

points. This dead-time period is essential because without it, the MOSFET driving one half of the transformer primary would still be switching off while the MOSFET driving the other half was switching on. As a result, the MOSFETs would be destroyed as they would effectively create a short circuit across the 12V supply.

One of the error amplifiers in IC1 is used to provide the under-voltage cut-out feature. This is done by connecting its pin 2 inverting input to the +12V rail via a voltage divider consisting of 10kΩ and 8.2kΩ resistors. The non-inverting input at pin 1 connects to IC1's internal 5V reference at pin 14 via a 4.7kΩ resistor.

When the voltage at pin 2 drops below 5V (ie, when the battery voltage drops below 9V), the output of the error amplifier goes high and the PWM outputs at pins 9 and 10 go low, shutting the circuit down. Note the 1MΩ resistor between the non-inverting input at pin 1 and the error amplifier output at pin 3. This provides a small amount of hysteresis so that the output of the error amplifier does not oscillate at the 9V threshold.

The second error amplifier in the TL494 is used to control the output voltage of the DC-DC converter. The feedback voltage is derived from the positive side of the bridge rectifier and fed via a voltage divider consisting of two 270kΩ resistors and trimpot VR1 in series, plus a 10kΩ resistor to ground. The resulting voltage is then

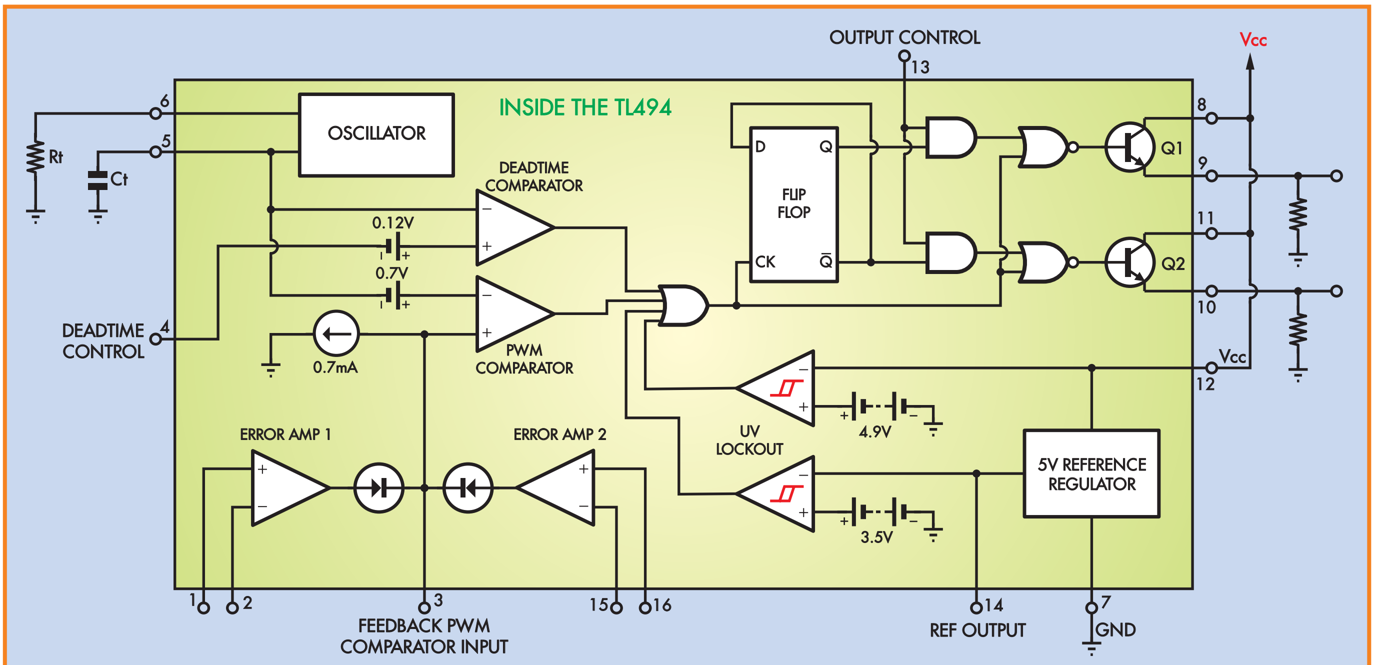


Fig.5: the internal circuit of the TL494 switch-mode pulse-width modulation (PWM) controller. It is a fixed-frequency PWM controller containing a sawtooth oscillator, two error amplifiers and a PWM comparator. It also includes a dead-time control comparator, a 5V reference and output control options for push-pull or single-ended operation.

fed to pin 16 of IC1 and compared to the internal 5V reference, which is applied to pin 15 via a 4.7kΩ resistor.

Normally, the attenuated feedback voltage should be close to 5V. Should this voltage rise (due to an increase in the output voltage), the output of the error amplifier also rises and this reduces the output pulse width. Conversely, if the output falls, the error amplifier's output also falls and the pulse width increases.

The gain of the error amplifier at low frequencies is set by the 1MΩ feedback resistor between pins 3 and 15 and by the 4.7kΩ resistor to pin 14 (V_{REF}). These set the gain to about 213. At higher frequencies, the gain is set to about 9.5 by virtue of the 47kΩ resistor and 100nF capacitor in series across the 1MΩ resistor. This reduction in gain at the higher frequencies prevents the amplifier from responding to hash on the supply rails.

The 10kΩ resistor and 1nF capacitor at pins 6 and 5 respectively set the internal oscillator to about 120kHz. This is divided by two using an internal flipflop to give the resulting complementary (anti-phase) output signals at pins 9 and 10. The resulting switching rate of the MOSFETs is 60kHz.

Pin 4 of IC1 is the dead-time control input. When this input is at the same level as V_{REF}, the output transistors are off. As pin 4 drops to 0V, the dead-time decreases to a minimum. At switch on, the 10µF capacitor between V_{REF} (pin 14) and pin 4 is discharged and this initially holds pin 4 at 5V. This prevents the output transistors in IC1 from switching on.

The 10µF capacitor then charges via the 47kΩ resistor (between pin 4 and ground) and so the duty cycle of the output transistors slowly increases until full control is gained by the error amplifier. This effectively provides a soft start for the converter. The 1MΩ resistor between pins 4 and 13 has been included to provide more dead-time. It prevents the 10µF capacitor from fully charging to 5V and this increases the minimum dead-time period.

Complementary outputs

As stated, the complementary PWM outputs at pins 9 and 10 of IC1 come from internal emitter-follower transistors. These each drive external 10kΩ pull-down resistors and MOSFET drivers IC2a and IC2b, which can deliver up to 1.5A charge/discharge current into the MOSFET gates, for fast and clean switching.

Note the 100nF X2 capacitor and the 4700µF low-ESR capacitor between the centre tap of the transformer primary and ground. These are there to cancel out the inductance of the leads which carry current to the transformer. They effectively provide the peak current required from the transformer as it switches.

Transformer T1 is a relatively small ferrite-cored unit designed to be driven at high frequencies. This is a similar arrangement to that used in the *Ultrasonic Cleaner* (*EPE*, August 2012) and in the *Ultrasonic Anti-Fouling Unit For Boats* (*EPE*, September and November 2012). Its primary and secondary windings are wound using enamelled copper wire, with the number of turns set to provide the required output voltage.

In operation, the power MOSFETs alternately switch each side of the transformer primary to ground, so that the transformer is driven in push-pull mode. When Q1 is on, the 12V supply is across the top half of the primary winding, and when Q2 is on, the supply is across the bottom half. This alternating voltage is stepped up by the secondary and applied to a full-wave bridge rectifier comprising UF4007 ultra-fast recovery diodes D2-D5.

These ultra-fast diodes are necessary because of the high switching frequency of 60kHz. A 100nF X2 capacitor filters the 300V DC output and this is fed to the drain of MOSFET Q3

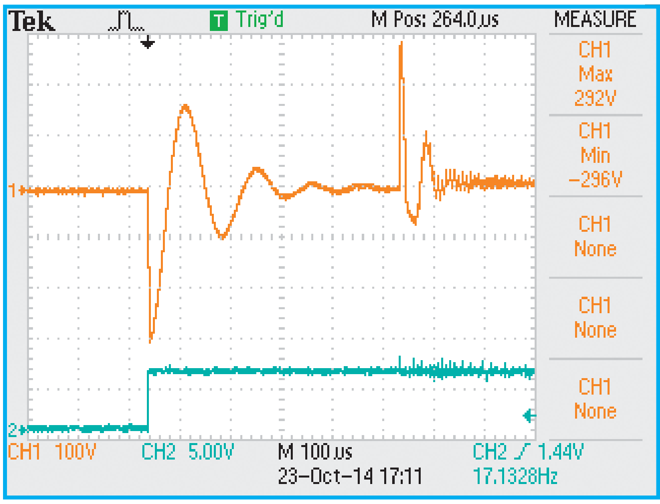


Fig.6: channel 1 (orange trace) of this scope shot shows the primary coil voltage at the coil+ output with multi-sparking disabled, while channel 2 (cyan) shows the input trigger signal. Note the –296V first spark voltage at the firing point and the +292V voltage excursion for the second spark 500µs later.

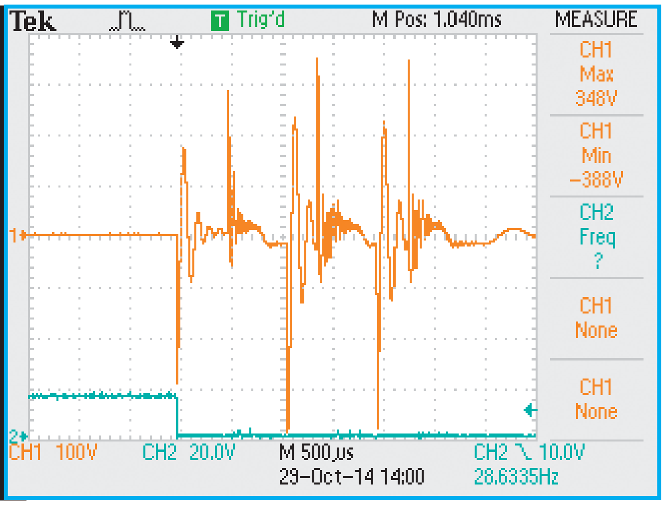


Fig.7: in this shot, channel 1 (orange) shows the primary coil voltage when six sparks are produced, while channel 2 (cyan) is triggered by the tacho signal.

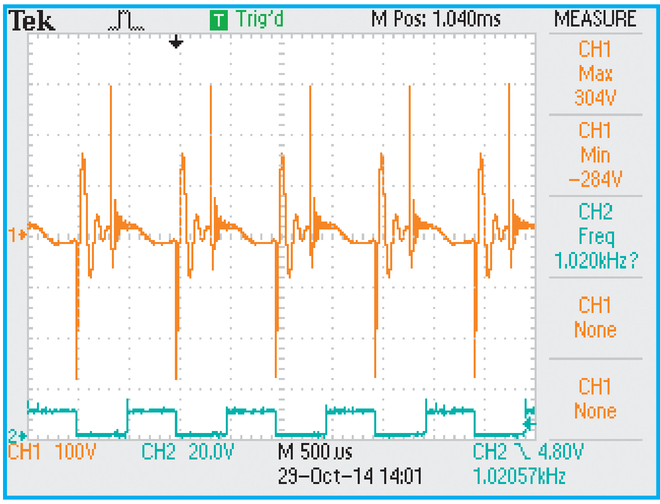


Fig.8: this scope shot shows that there is no drop off in the peak voltage applied to the coil (channel 1, orange) for a 1kHz input trigger frequency (channel 2, cyan).

and also to IC3, an L6571 half-bridge MOSFET driver and oscillator, via 75V zener diode ZD2 and two series 33kΩ 1W resistors.

IC3's supply at pin 1 is set to 15V by an internal zener diode. ZD2 is used to drop the 300V supply before feeding it to the 33kΩ resistors, so that each dissipates no more than 334mW.

Driving Q3

In order for MOSFET Q3 to fully turn on, its gate must be raised above its drain by several volts and this is the job of IC3, the L6571 half-bridge driver. It produces the necessary higher gate voltage using diode D6 and a 100µF capacitor (Cx) between Q3's source and pin 8.

Initially, IC3 starts with a 15V supply derived from the 300V rail, as mentioned above. Q4 is the first to be switched on and it pulls one side of capacitor Cx low. Cx then charges to the +15V supply via D6 and Q4.

When Q4 turns off and Q3 turns on, Q3 pulls pin 6 of IC3 up to the 300V rail and so pin 8 is jacked up above +300V by the 15V across the capacitor. The voltage across Cx is then maintained until next recharged via D6 and Q4 (note that pins 6, 7 and 8 of IC3 are floating outputs which can be shifted up to 600V above the pin 4 ground).

Cx needs to be relatively large (100µF) since it can be called on to keep its charge for up to 100ms during slow cranking of the motor. The totem-pole output of MOSFETs Q3 and Q4 drives the ignition coil primary via the 1µF X2 capacitor.

The 22Ω gate resistors slow the turn-on and turn-off times for Q3 and Q4, to limit transients when switching the 1µF capacitor.

Multi-sparking

Multi-sparking is possible because IC3 incorporates a self-oscillating section involving two comparators, as shown by its internal block diagram on Fig.4. The series resistor string sets the inputs of the two comparators at 2/3 and 1/3 of the 15V supply, while the external 4.7nF capacitor and 180kΩ resistor configure the two comparators as an astable multivibrator. It operates in a very similar way to a 555 timer IC connected in astable mode.

In our circuit, we have added diode D7 and another 180kΩ resistor in series. This ensures that the discharge period for the 4.7nF capacitor via one of the 180kΩ resistors is much longer than the charging period via both 180kΩ resistors and D7 when the latter is forward biased by pin 2.

Note that the 4.7nF capacitor is only tied to ground when transistor Q5 is switched on via the trigger circuit. Capacitor C1 is also connected to the collector of Q5. Initially, when Q5 is off, C1 is discharged and held at the pin 1 supply voltage (+15V) via the 13kΩ resistor at Q5's collector and the 33kΩ resistor at D8's anode. This last resistor pulls pin 3 of IC3 well above the upper threshold (2/3 the pin 1 supply) via D8. As a result, pin 2 goes low but the 4.7nF capacitor cannot be discharged and so IC3 doesn't oscillate.

Table 1: RPM vs spark number and duration

RPM	Distributor trigger frequency (Hz)	No. of sparks	Multiple spark duration (crankshaft degrees)
4-Cylinder 4-Stroke engines			
600	20	6	8
900	30	6	13
1200	40	6	16
1500	50	6	20
2250	75	4	19
3000	100	4	25
4500	150	4	37
9000	300	2	21
15,000	500	2	36
6-cylinder 4-stroke engines			
400	20	8	8
600	30	8	12
800	40	6	11
1000	50	6	14
1500	75	6	21
2000	100	4	16
3000	150	4	24
6000	300	2	14
10,000	500	2	22
8-cylinder 4-stroke engines			
300	20	14	11
450	30	12	13
600	40	10	15
750	50	10	18
1125	75	8	21
1500	100	8	20
2250	150	6	29
4500	300	4	32
7500	500	2	15

This in turn means that MOSFET Q4 is off and Q3 is on.

When Q5 switches on due to an input trigger signal, D8's anode is pulled low via C1. Thus, the 33kΩ resistor is temporarily out of the oscillator circuit and so the 4.7nF capacitor is charged and discharged via the components at pin 2, as previously discussed. Q4 and Q5 now switch on and off alternately and so the coil is fired repetitively.

C1 now charges again via the 33kΩ resistor and when its voltage reaches the upper threshold of pin 3's input, the oscillator stops as described before.

Note that at high RPM, Q5 is on for less time than it takes C1 to recharge via the 33kΩ resistor and switch off IC3's oscillation. The instant this transistor switches off, IC3 stops oscillating since C1 is immediately pulled high. This is a fail-safe condition to prevent sparks designated for one cylinder from accidentally firing the next cylinder in sequence.

The trigger circuit also drives transistor Q6 to provide a low voltage (+12V) tachometer output. This is necessary, since a tachometer connected to the coil would otherwise give false readings.

Disabling multi-spark mode

If you wish, the multi-spark feature can be easily disabled by removing C1 and replacing the 4.7nF capacitor with a 15nF capacitor instead.

This modification now causes IC3 to produce a single 0.5ms pulse to switch on Q4. This fires the coil in one direction when Q4 switches on and in the other direction when Q3 switches on.

A metal-oxide varistor (MOV1) is connected across the coil to quench the high-voltage transient which will occur if the coil is left open-circuit on the secondary. Leaving the coil output open-circuit can cause it to break down internally and this quickly leads to failure.

Two 680kΩ resistors are connected in series across the 1μF X2 output capacitor to discharge it should the coil become disconnected from the circuit. This is a safety measure since a 1μF capacitor charged to 300V can produce a very nasty shock.

Trigger inputs

Because this *Multi-Spark CDI* is intended for use with a wide range of engines, we have made it compatible with six different trigger sources. These are all shown on the main circuit of Fig.4.

The points input circuit (a) simply comprises a 100Ω 5W resistor connected to the 12V supply. This resistor provides a wetting current for the points to ensure their contacts remain clean. The points connect to the trigger input associated with Q5.

The Hall effect or Lumenition (optical trigger) module input (b) uses a 100Ω supply resistor (R2) to the +12V rail. This resistor limits the current into the internal clamping diode of the Hall effect or Lumenition unit. The 1kΩ resistor (R3) pulls the output voltage up to +5V when the internal open-collector transistor is off. Conversely, the output voltage falls to near 0V

Beware of similar ICs!

Note that there are similar half-bridge self-oscillating MOSFET drivers to the L6571, such as the IR2155 – note that the IR2155 is now an obsolete part.

There are also what may appear to be similar drivers. These include the IR2153, the IR25603 and the IRS2153. Don't use these in this circuit – they won't work properly!

The *High-Energy Multi-Spark CDI* is housed in a rugged diecast metal case which provides good heatsinking for the four MOSFETs. It's mounted in a splash-proof location in the engine bay, preferably where air can flow over it and well away from the hot exhaust manifold and exhaust pipes.

when the internal transistor turns on.

The engine management input (c) is very straightforward; the 5V signal output from the vehicle's engine management unit simply connects to the trigger input.

Reluctor triggering

The reluctor input circuit (d) is the most complex. In operation, the reluctor coil produces an AC signal which switches transistor Q7 on and off. This works as follows: with no reluctor voltage, transistor Q7 is biased on via trimpot VR2 and the 47kΩ resistor to its base. The actual voltage applied to Q7's base depends on the 10kΩ resistor connected to the top of the reluctor coil and on the internal resistance of the reluctor.

Trimpot VR2 is included to cater for a wide range of reluctor resistance values. In practice, VR2 is adjusted so that Q7 is just switched on when there is no signal from the reluctor. When the signal goes positive, Q7 remains switched on. When the signal goes negative, Q7 is switched off.

Resistor R4 provides loading for the reluctor, while the 470pF capacitor shunts any high-frequency signals. The 2.2nF capacitor speeds up Q7's switch-on and switch-off times.

Optical triggering

Two optical (photoelectric) triggering versions are catered for, one for a Crane pick-up (e) and one for a Piranha pick-up (f). The Crane trigger has a common-ground connection, while the Piranha has a common positive. For the Crane trigger, resistor R5 feeds current to the internal LED from the +5V supply, while R3 functions as a pull-up resistor for the photodiode.

Similarly, for the Piranha trigger, R4 is the current resistor for the LED, while R6 functions as pull-down for the internal photodiode.

That's all for this month. Next month, we'll describe the PCB assembly and the test and installation procedures.

Warning – High Voltage!

This circuit produces an output voltage of up to 300V DC to drive the coil primary and is capable of delivering a severe (or even fatal) electric shock. DO NOT TOUCH any part of the circuit or the output leads to the coil from CON2 while power is applied.

To ensure safety, the PCB assembly must be housed in the recommended diecast case. This case also provides the necessary heatsink for the four MOSFETs – see Part 2 next month.

Win one of three Microchip Curiosity Development Boards

EVERYDAY PRACTICAL ELECTRONICS is offerring its readers three chances to win a Microchip Curiosity Development Board. This board is a cost-effective, fully integrated 8-bit development platform targeted at first-time users, makers and those seeking a feature-rich, rapid prototyping board.

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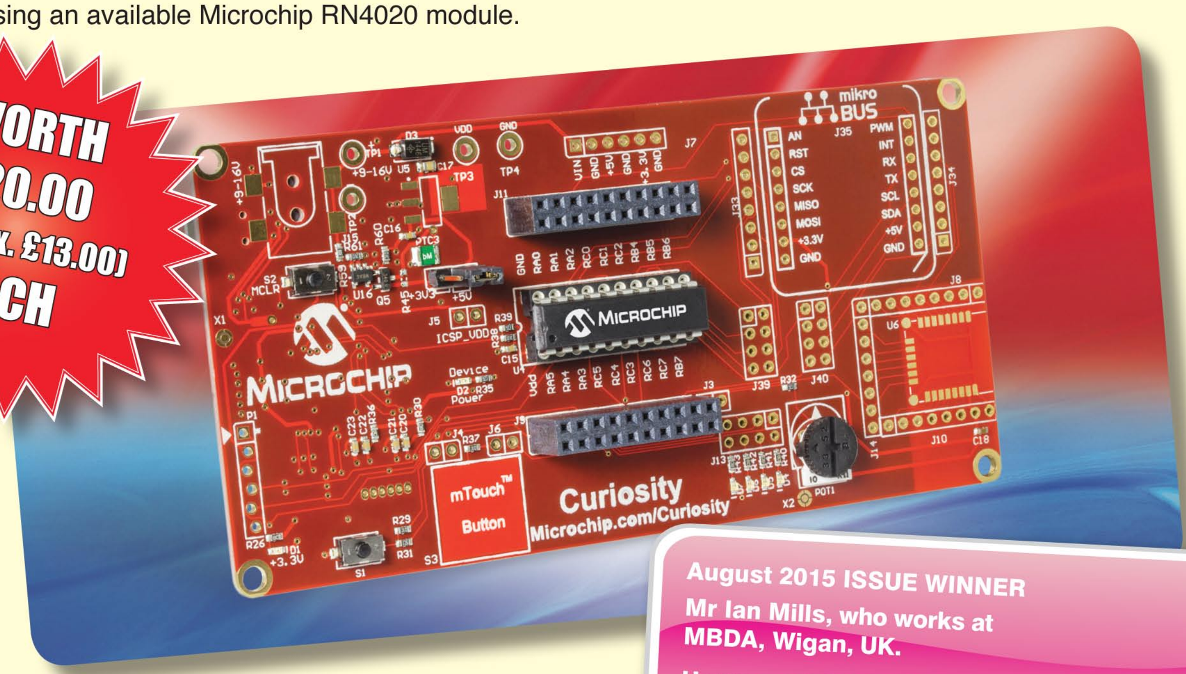

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Find faults in cables with this:

By JIM ROWE

TDR Dongle For Oscilloscopes

How would you like to be able to track down faults in coaxial and other cables using time-domain reflectometer or 'TDR'? If you have a reasonably fast oscilloscope (20MHz or more), this low cost *TDR Dongle* will let you do a lot of basic cable fault finding very easily.

THE TIME-DOMAIN reflectometry (TDR) concepts behind this project are surprisingly simple, but are not frequently encountered outside specialist areas of electronics. If you need more information than is found in this article, then a reasonably straightforward introduction to the topic can be found here: **https://en.wikipedia.org/wiki/Time-domain_reflectometer**.

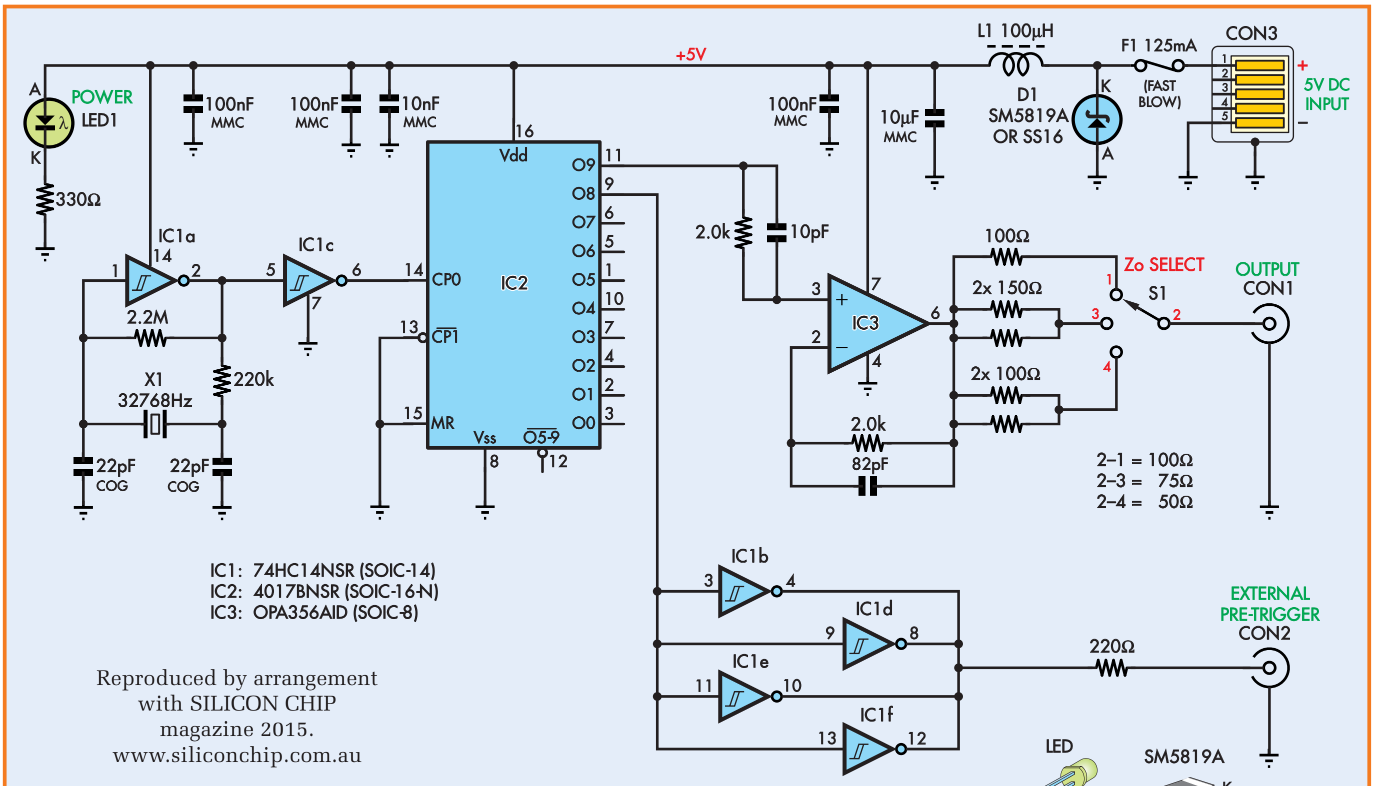
Most TDRs consist of two key components: (1) a voltage step or pulse generator to produce the electrical stimulus which is fed into the cable to be tested and (2) an oscilloscope to look for any reflections or echoes of that stimulus which may be returned by faults or discontinuities in the cable.

If the scope is reasonably fast and also calibrated, this allows you to work out factors like how far along the cable a fault or discontinuity may lie and the kind of fault it is.

High-end commercial TDRs have both of these key components built into the same case, plus some computing power to save you having to convert delay times into cable distances and step amplitudes into impedance levels. But they also carry a fairly stiff price tag, making it hard to justify their cost if you only need to use a TDR occasionally.

But if you have a reasonably good scope, you are well on the way to having a usable TDR. So in this article we're describing a voltage step generator capable of being used with almost any reasonably fast scope to produce a 'Step TDR'.

As shown in the photos, the project is based on a very small PCB with a small number of mainly SMD components mounted on it. This is housed in



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TIME DELAY REFLECTOMETER DONGLE

Fig.1: the complete circuit. A 32.768kHz crystal oscillator (IC1a) drives synchronous counter IC2 to produce 30.5µs-wide voltage steps which then pass through op amp buffer stage IC3. Switch S1 then selects one of three source resistances, to suit the impedance of the cable being tested.

a small ABS instrument case measuring 90 × 50 × 24mm – only a little larger than a USB dongle. And since it can be powered from a USB port of your DSO or PC (or a USB charger), that's why we have called it a *TDR Dongle* instead of a 'TDR Adaptor'.

Put simply, the *TDR Dongle* generates repetitive voltage steps which have a duration of 30.5µs (microseconds) at a rate of 3.278kHz – so there are gaps of 274.5µs between them. The 30.5µs duration of the steps is equal to 30,500ns, which allows for viewing reflections in commonly used 'solid PE dielectric' coaxial cables more than 3km long.

The *TDR Dongle's* main output delivers the steps with an amplitude of around 3.5-4V peak, via a choice of three source resistances: 50Ω, 75Ω or 100Ω. This allows it to be used for measurements on most commonly available cables and also means that the effective step amplitude at the input to the cable being tested will be around 1.75-2V peak when the generator's source resistance is correctly matched to the impedance (Zo) of the cable.

In addition to the main step output, there's a second external 'Pretrigger' output which provides a falling (negative-going) step output which is 30.5µs ahead of the main output step. The idea of this is that when you're using high sweep speeds to examine reflections relatively close to the step generator end of a cable, it should allow pre-triggering of your scope via its external trigger input, for greater reliability and improved resolution.

How it works

To see how the *TDR Dongle* works, turn to the circuit diagram of Fig.1. Only three ICs are involved, plus a handful of other components. IC1 is a 74HC14 hex Schmitt inverter, with one of its six inverters (IC1a) operating as a clock oscillator in conjunction with quartz crystal X1, a tiny SMD device resonating at 32.768kHz. A second inverter, IC1c, is used as an isolating buffer, to maintain a constant load on the output of IC1a.

The buffered 32.768kHz output from IC1c is then fed to the clock input of IC2, a 4017B synchronous Johnson decade counter which counts continuously. As a result, output O9 of IC2 (pin 11) goes high for 30.5µs after every nine clock pulses – during which each of the other outputs (ie, O0 – O8) goes high in turn.

So pin 11 of IC2 switches high every 305µs and remains high for 30.5µs each time. This is how our voltage steps are generated.

These voltage steps from pin 11 of IC2 are fed to the non-inverting input of IC3, an OPA356 high-speed video amplifier being used here as a cable driver. The connection is not made directly but via a paralleled 2.0kΩ resistor and 10pF capacitor combination.

IC3 is connected as a unity-gain voltage follower, with the paralleled 2.0kΩ resistor and 82pF capacitor in the negative feedback line being included to achieve high stability, a short rise-time and minimum overshoot. So the output voltage step appears at pin 6 with an amplitude of about 3.5V, limited by IC3's input common-mode range of GND to Vcc – 1.5V.

Switch S1 allows selection of one of three possible output series resistances: 50Ω, 75Ω or 100Ω. This allows the source resistance of the step generator to be matched to the characteristic impedance (Zo) of the type of cable

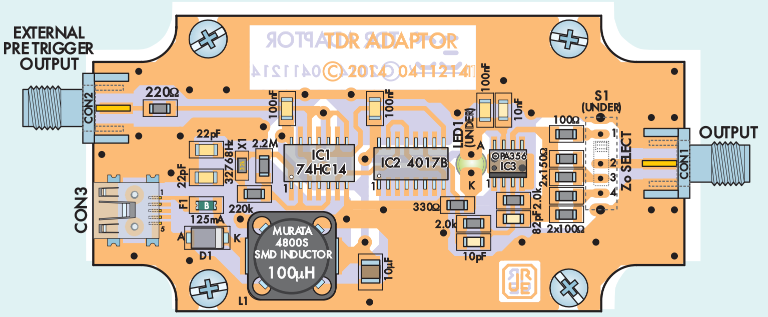


Fig.2: the PCB overlay diagram, shown actual size. Most of the parts are SMDs and are mounted on the top of the PCB. LED1 and selector switch S1 are mounted underneath.

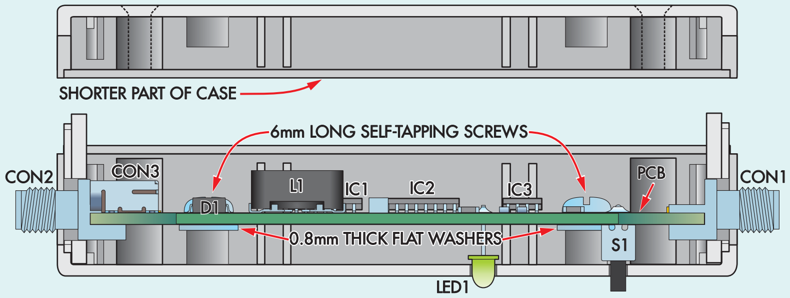
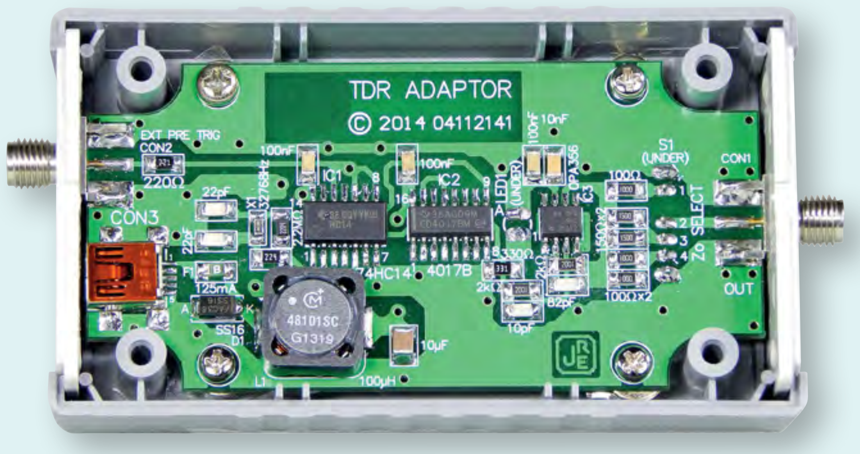


Fig.3: an internal side view showing how the *Dongle's* PCB assembly is mounted in the case. Note that a 0.8mm-thick flat washer needs to be placed on the top of each moulded PCB mounting post, as shown.



All of the SMD components used in the *TDR Dongle* can be seen in this photo, reproduced close to actual size. Use this together with the diagrams above as a guide to assembly.

you want to test. The output steps pass through the selected resistance to appear at output connector CON1, an SMA socket.

The external pre-trigger output is derived from the O8 output (pin 9) of IC2, which goes high 30.5µs before the O9 output and also remains high for 30.5µs – falling to zero just before each main step.

The remaining inverters inside IC1 are connected in parallel and used as an inverting buffer for the pre-trigger pulses, with their buffered output taken to CON2 via a 220Ω protective series resistor.

So the output pulses from CON2 are negative-going, rising back to zero simultaneously with the rise of each main output step.

The rest of the circuit is straightforward. The 5V DC power needed by the circuit is brought in via CON3, a mini-USB type B socket. Fuse F1 and diode D1 are provided purely for reverse polarity protection, while L1 and the 10µF capacitor are used for filtering the +5V line. LED1 is used to indicate when the adaptor is powered up and operating.

Construction

As stated, all the parts are mounted on a small PCB, available from the *EPE PCB Service*, coded 04112141 and measuring 81 × 41mm. Fig.2 shows the parts layout diagram.

The only parts which aren't surface-mount devices (SMDs) are switch S1 and LED1. These are both in through-hole packages and are mounted on the underside of the PCB. Note that S1 is actually a sub-miniature slider switch, although we've shown it in the schematic of Fig.1 as a rotary switch for greater clarity.

We suggest that you add the parts to the PCB in the following order, to make it easier:

- Fit power connector CON3, soldering its five tiny connection leads to their matching pads on the PCB before you solder its four 'feet' to the larger pads.
- Fit the SMD resistors to the PCB, followed by the capacitors.
- Fit fuse F1, followed by diode D1 which goes alongside it.
- Solder IC1, IC2 and IC3 to the top of the PCB, taking care with their orientation and also making sure that all their pins are soldered to their matching pads. Use solder wick and no-clean flux paste to remove any inadvertent solder bridges between the pins.
- Filter inductor L1 is the last SMD component to add to the board. That's because it's the largest and tends to limit access to some of the smaller components if it's fitted earlier.

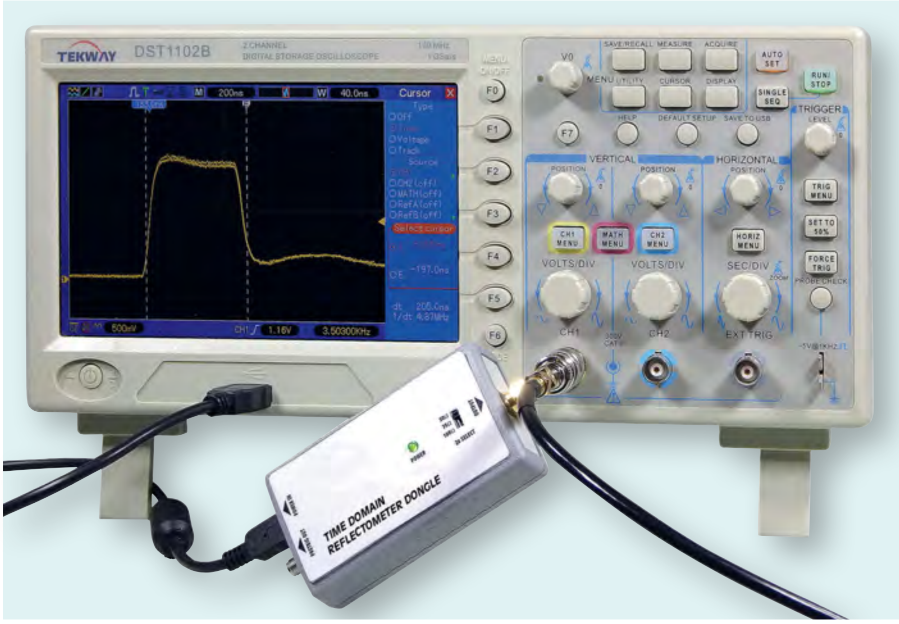
  Note that L1 is mounted with its two continuous contact strips on the east and west sides (with the PCB oriented as shown in Fig.2), so that they can be soldered to the pads on the top of the PCB.
- Install LED1 and switch S1, the two through-hole parts. These mount under the PCB, with their leads and pins passing up through the matching holes and soldered to the pads on the top of the PCB.

  Note that S1 should be pushed up until its underside is hard against the bottom of the PCB, before soldering its pins and its two end mounting lugs to the top copper. By contrast, LED1 is not pushed hard up against the PCB, but fitted with the underside of its lens about 3-4mm below

the PCB. This ensures that lens just protrudes through its matching hole in the case after final assembly.

- Fit connectors CON1 and CON2. These are 'straight through' SMA sockets which mount on the edge of the PCB at opposite ends. When mounting these, it's a good idea to first solder their centre pins to the matching pads on the top of the PCB, so they are then held in position while you solder their outer earth.

The internal side view diagram of Fig.3 should help in making the above description a little clearer. The PCB assembly should now be complete and can be put aside while you prepare the case.



This photo shows the *TDR Dongle* being used with a Tekway DST-1102B DSO. It's coupled to the scope's CH1 input via a BNC plug-to-plug adaptor. Because the *Dongle* is very light, this is a good way to use it.

Preparing the case

There's not a lot of work involved in preparing the case, as shown by the drilling and cutting diagram of Fig.4. There are only five holes in all: two in the deeper part of the case (which becomes the top of the *TDR Dongle*), two in the lefthand end panel (for access to CON2 and CON3), and the remaining one in the righthand end panel for access to CON1.

There's one point to note before you start on the rectangular holes in the end panels. The end panels are effectively polarised, as shown in Fig.4 – they're tapered between one longer side to the other, which means that they'll only fit into the deeper part of the case one way around (the side with the small central notch in the flange must face upwards, towards the less-deep part of the case).

So make sure you have the end panels oriented correctly before you mark the positions of the holes and (especially) before you begin to drill and cut them out.

Only one of the five holes is circular – the 3.5mm diameter hole for LED1 in the main part of the case. The others are all rectangular, so you'll need to use a small (1.5-2mm) drill to make a series of holes around the inside of their rectangular outlines first, to allow you to cut away the material inside. Then you can use small jeweller's files to neaten them up and bring them out to their final shape.

Once you have made all of the cutouts in the case and its end panels, you can make a front panel to attach to the top of the case and to this end we've prepared the small artwork shown as Fig.5. This can be photocopied and covered with clear adhesive tape to protect it from dirt and finger grease, before cutting it to size and then attaching it to the deeper part of the case using double-sided tape or silicone.

Alternatively, you can download the artwork as a PDF file from the *EPE* website and print it out.

Final assembly

Once you have prepared the case, the final assembly is straightforward. The first step is to place the deeper part of the case down on the workbench, with its outer dress front panel underneath. Then place a small flat washer (0.8mm thick, 3.5mm inside diameter) centrally on the top of each

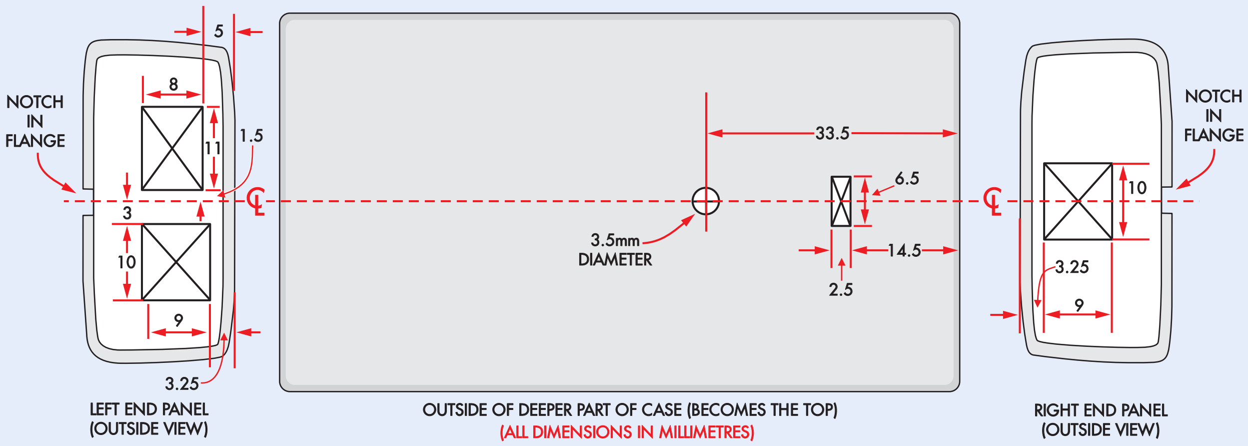


Fig.4: the drilling and cutting details for the case. Note that the end panels are polarised – make sure you orient them as shown before you make their rectangular cutouts.

Parts List

1 ABS case, 90 × 50 × 24mm
1 double-sided PCB, available from the *EPE PCB Service*, code 04112141, 81 × 41mm
2 SMA sockets, edge-mounting (CON1,2)
1 mini USB type B socket, SMD, FCI 10033525-N3212MLF (CON3)
1 100µH 1.6A SMD inductor (L1), Murata 48101SC
1 mini slider switch, SP3T (S1), C&K OS103011MS8QP1
1 32768Hz crystal, SMD (X1)
1 125mA fast blow 1206 SMD fuse (F1), Littelfuse 0466.125NR
4 6G × 6mm self-tapping screws
4 3.5mm ID flat washers, 0.8mm thick

Semiconductors
1 74HC14NSR hex Schmitt-input inverter, SOIC-14 package (IC1)
1 4017BM decade counter, SOIC-16-N package (IC2)
1 OPA356AID video amplifier, SOIC-8 package (IC3)
1 3mm green LED (LED1)
1 60V 1A Schottky diode, DO214AC SMD package (D1) (SS16 or SM5819A)

Capacitors
1 10µF MLCC, SMD 1210, X7R dielectric, 16V rating
3 100nF MLCC, SMD 1206, X7R dielectric, 50V rating
1 10nF MLCC, SMD 1206 X7R dielectric, 16V rating
1 82pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating
2 22pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating
1 10pF ceramic, SMD 1206, C0G/NP0 dielectric, 50V rating

Resistors (0.25W 1% SMD 1206 pkg)

1 2.2MΩ	1 330Ω	3 100Ω
1 220kΩ	1 220Ω	
2 2.0kΩ	2 150Ω	

of the four moulded-in PCB mounting posts. These are needed to provide additional spacing.

Next, fit the two end panels over the connectors at each end of the PCB and lower the PCB and end panels together into the deeper part of the case, with the end panels fitting into the moulded slots at each end. Do this carefully, so you don't accidentally knock the spacing washers off their posts. You should find that when the PCB is sitting on the washers, LED1 and S1's actuator will just be protruding through their holes in the front panel underneath – see Fig.3.

After that, it's simply a matter of fitting four small 6G × 6mm self-tapping screws to secure the PCB assembly and then fitting the other part of the case. This case section is also effectively polarised, so you need to fit it the correct way around.

The final step is fitting the four 15mm-long countersink-head self tapping screws supplied with the case, to hold everything together. Your *TDR Dongle* should then be complete and ready for use.

Connecting up

The first step in connecting the *TDR Dongle* is to provide it with 5V DC power, via a standard USB type A to mini USB type B cable (note that the cable should have a USB-Mini type B plug at the *Dongle* end, not a USB-Micro plug). The mini plug end mates with CON3 on the *Dongle*, while the type A plug on the other end will mate with a USB port on your scope, your PC or even a USB charger plugpack.

Now you need to make the connections between the main output of the *TDR Dongle*, one input of your scope and the input end of the cable you want to test. This is not quite as straightforward because to a large extent, the neatest and most efficient way to make the connections will depend on the connectors being used on the cable to be tested.

The main point to keep in mind is that both the scope input and the input end of the cable to be tested should be connected to the output of the *TDR Dongle* using the smallest possible number of connectors, 'series adaptors' and couplers. That's because connectors, adaptors and couplers always introduce a small discontinuity of their own.

The two sample configurations shown in Fig.6 are intended to guide you in using the *TDR Dongle* to test cables fitted with two of the most common types of connector. The upper configuration shows the neatest and most efficient approach when you're going to test cables with BNC connectors, while the lower one shows the most efficient approach when the cables to be tested are fitted with SMA connectors.

Note that in both cases we've shown the cable running to the scope input fitted with BNC connectors, because most scope inputs are fitted with BNC connectors anyway.

As you can see, the simplest approach in the 'BNC world' is to use an SMA plug-to-BNC socket adaptor right at the *TDR Dongle's* output, connected directly to a BNC plug-to-2 × BNC sockets T-adaptor. The cable to be tested then attaches to one of the T-adaptor's sockets, while the short cable running to the scope input attaches to the other socket.

On the other hand, when the cable(s) to be tested have SMA connectors, the simplest approach is to connect an SMA plug-to-2 × SMA sockets T-adaptor directly to the *Dongle's* output socket, as shown in the lower configuration of Fig.6. The cable to be tested is then attached to one of the T-adaptor's sockets, with the scope input cable connecting to the other socket via an SMA plug-to-BNC socket adaptor.

What if you want to test cables fitted with N-type or F-type connectors? In

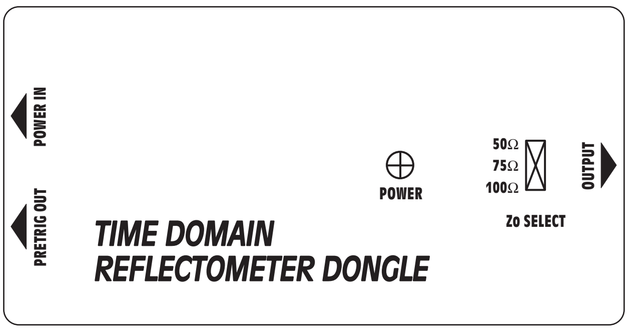


Fig.5: the full-size front-panel artwork for the *TDR Dongle*, reproduced. It can be photocopied or you can download it in PDF format from the *EPE* website and print it out.

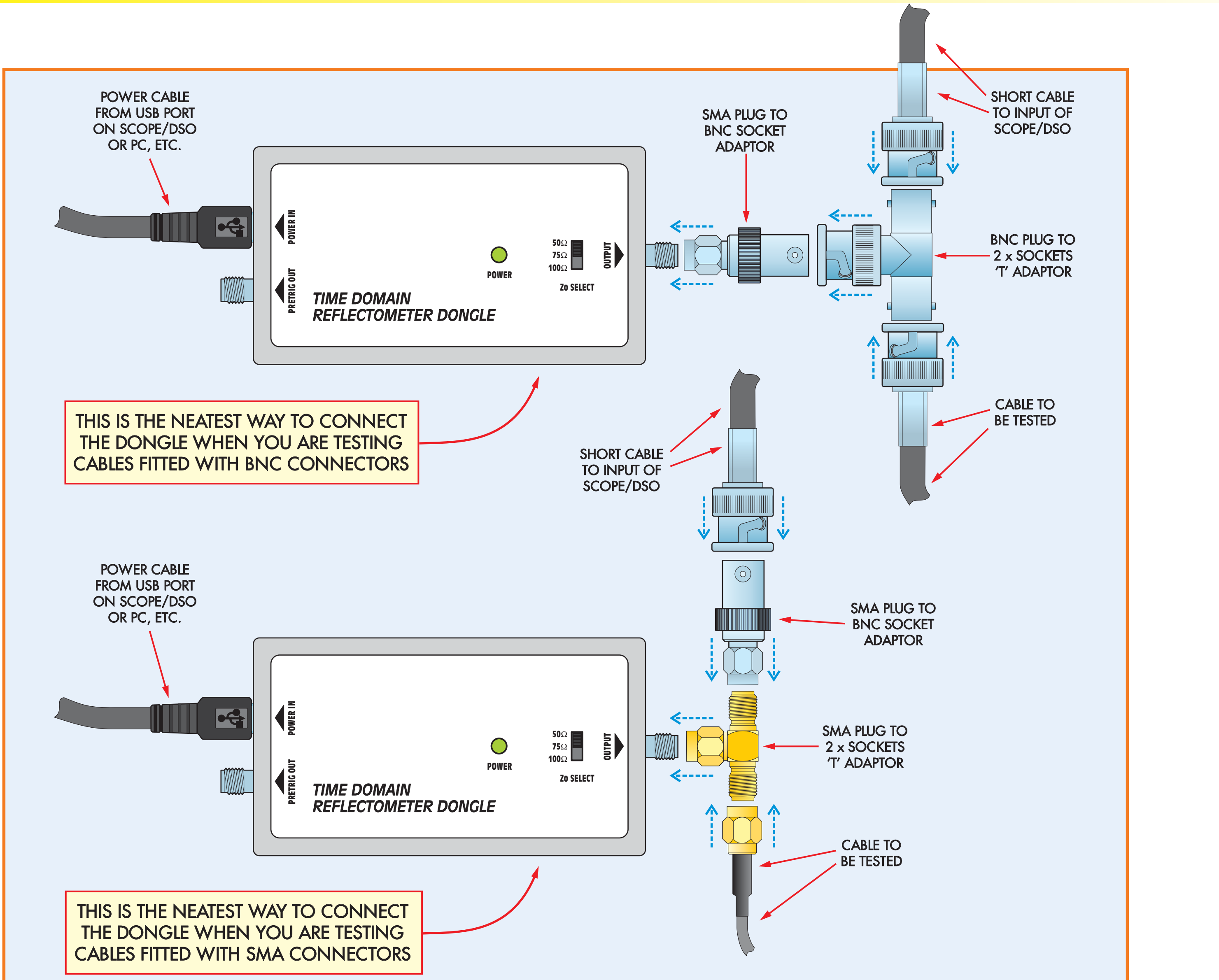


Fig.6: here are two neat and efficient ways to connect the *Dongle* when using it to test cables. A BNC plug-to-plug adaptor can be used instead of the short cable running to the scope/DSO input, to minimise reflections even further.

these cases, the simplest approach is to again use the lower configuration in Fig.6. However, instead of connecting the cable to be tested directly to the lower socket of the SMA T-adaptor, connect it via an SMA-to-N-type or an SMA-to-F-type adaptor.

The same approach will also apply if you need to test cables with old UHF connectors or even Belling-Lee (TV RF) connectors.

What about Ethernet cables?

How could you use the *TDR Dongle* to check Ethernet or other twisted-pair cables fitted with RJ-45 or similar connectors? To do this, you'd probably need to make up a special T-adaptor of your own, perhaps with one or more switches to allow you to select each cable pair to test them. You may also need to build in one or more additional resistors in series with the *TDR Dongle's* output, to allow better matching to the higher Zo of the cable pairs.

So using the *TDR Dongle* is likely to call for a range of cable adaptors. Fortunately, many of these are available from the usual suppliers, although you will probably have to order some of the more exotic adaptors from firms like element14. To help you in this regard, here are the element14 order numbers for two of them:

1) SMA plug-to-BNC socket adaptor, (50Ω): order code 116-9564
2) SMA plug-to-2 × SMA socket T-adaptor: order code 213-5972

Putting it to use

There's not a great deal involved in using the *TDR Dongle* for cable testing. The main steps are these:

1) Connect it up as shown in one of the configurations of Fig.6.
2) Set S1 on the *TDR Dongle* (Zo SELECT) to match the characteristic impedance of the cable you want to test.
3) Power up your scope and set the timebase's speed to around 1µs/division and a vertical sensitivity which gives about 5.0V full deflection.
4) Set the scope's triggering for a rising edge, at a level of around 1.25V. Alternatively, if you're going to make use of the *TDR Dongle's* pretrigger output connected to the scope's external trigger input, set it for a falling edge and a level of around 2.5V.
5) Apply power to the *TDR Dongle* and observe the screen of the scope, looking for any reflection steps if there are any to be seen.

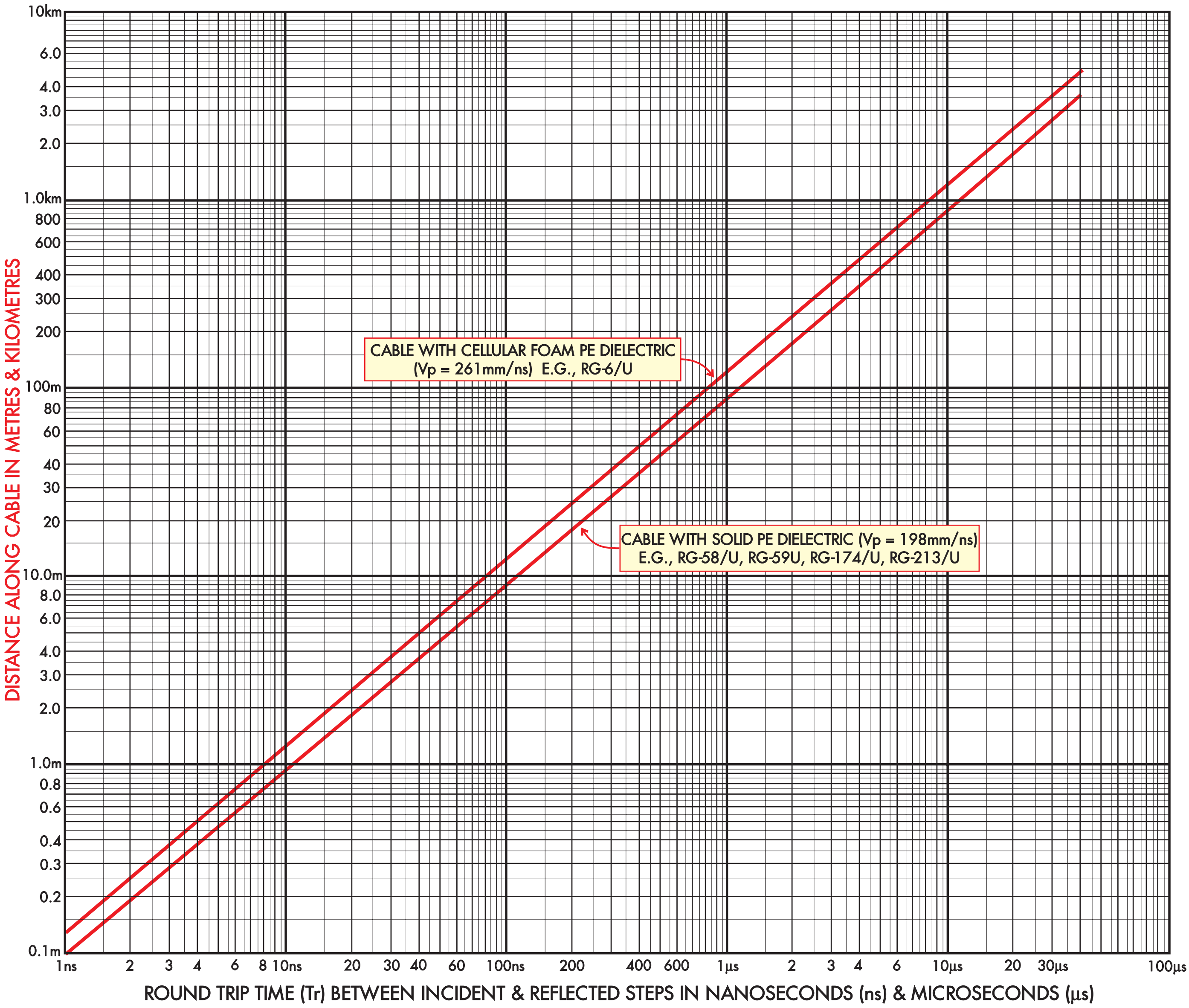


Fig.7: this graph makes it easy to work out the distance of a discontinuity along a cable once you know the round-trip reflection time as displayed on a scope. The lower red line should be used for solid PE dielectric cables (the most common type), while the upper line is for cables using cellular foam PE dielectric.

6) If any reflection steps are evident, you should then be able to determine what kind of discontinuity they're caused by and by measuring the time between the *Dongle's* incident step and the reflection step, you should be able to calculate its distance along the cable – knowing the cable's velocity factor.

This photo shows three of the cable adaptors you're likely to need when using the *TDR Dongle*: a 50Ω SMA plug-to-BNC socket adaptor (left); an SMA plug-to-2 × SMA sockets T-adaptor (centre); and an N-type socket-to-SMA plug adaptor (right).

To help you in working out the distance of a discontinuity along the cable from the time difference between the incident and reflected steps without having to turn to your calculator, we have prepared the graph shown in Fig.7. This shows the relationship between inter-step transit time (Tr) and the corresponding distance along the cable, for the two most common types of coaxial cable in current use.

You will also be able to work out the effective impedance of any particular continuity from the relative amplitudes of the incident step Ei and the reflected step Er – together with the polarity of Er, of course. But you're going to have to work this out using the following expression:

$$Z_{load} = -Zo \times (Ei + Er) \div (Er - Ei)$$

If your cable has either an open circuit or a short circuit as the discontinuity, this will be very easy to spot. With an open circuit, Er will have the same amplitude as Ei and the same polarity. A short circuit will result in Er again having the same amplitude as Ei but in this case with reversed polarity.

Some test example are shown in the scope screen grabs of Figs.8-11. These were captured using the prototype

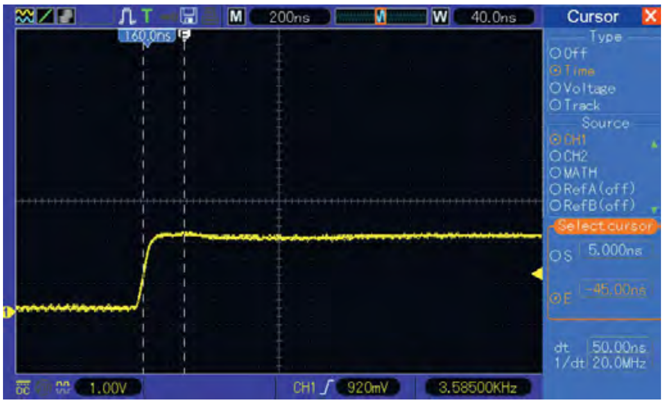


Fig.8: this screen grab shows the display when the *Dongle* was used to check a 4.6m-long SMA-SMA cable correctly terminated at the far end with a 50Ω termination. There are no reflections!

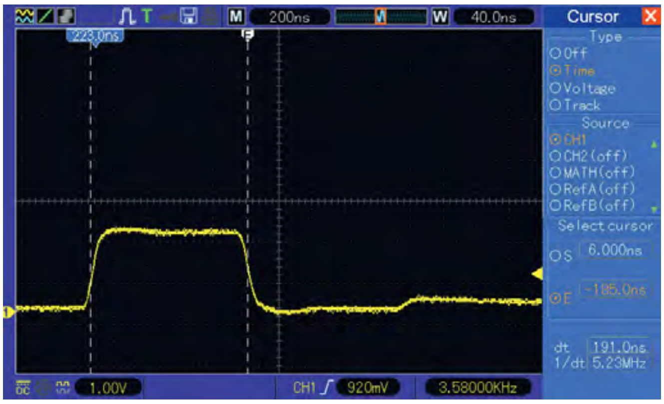


Fig.9: in comparison with Fig.8, this scope grab shows the display when testing an 18m-long SMA-SMA cable with a short circuit at the far end. The step falls back to zero after about 191ns, as you'd expect.

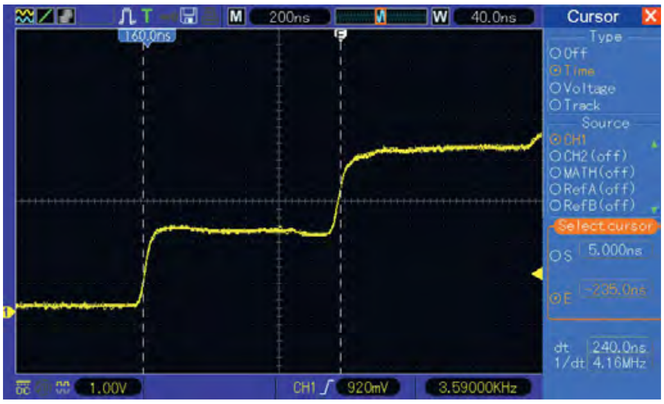


Fig.10: this scope grab shows the display when testing a 22.6m long SMA-SMA cable which was open-circuited at the far end. In this case, the step jumps up to twice its initial value, after about 240ns.

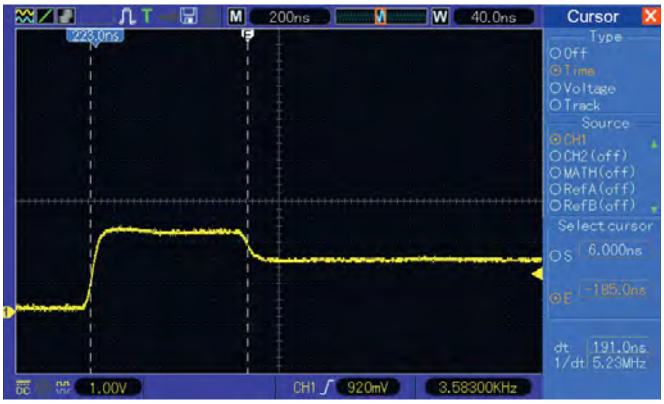


Fig.11: finally, here's the display when testing an 18m long SMA-SMA cable terminated in a 25Ω load instead of the correct 50Ω. As you can see, there's a step down by about 1/3 of the initial value, about 191ns from the start.

TDR Dongle hooked up to a Tekway DST1102B DSO.

We checked three different RG-58/U cables, all fitted with SMA connectors. Fig.8 shows the display with a 4.6m cable, which was correctly terminated in 50Ω at its far end. As you can see, the step continues smoothly way past the 50ns point corresponding to this cable length (indicated by the second vertical cursor), showing that the cable was indeed correctly terminated.

Compare this with the display in Fig.9, which shows an 18m-long cable with a short circuit at the far end. In this case, the step drops back to zero about 192ns from the start and if you check with the chart of Fig.7, you'll see that this time corresponds to a cable length of very close to 18m.

Fig.10 shows the display with a 22.6m-long cable with an open circuit at the far end. Here the step jumps up to twice its initial value, after a reflection time of about 240ns. If checked against Fig.7, you'll see that this corresponds to a cable length of very close to 22.6m.

Specification

- A low-cost voltage step generator for use with an oscilloscope to enable time-domain reflectometry measurements of coaxial cables.
- The main output provides repetitive voltage steps with a duration of 30.5µs, allowing for observation of reflections over cable lengths of up to just over 3km (in common cables with 'solid PE' dielectric). Step rise-time is approximately 26ns.
- Output impedance is selectable between 50Ω, 75Ω or 100Ω, to suit most common coaxial cables.
- A second output provides negative-going steps 30.5µs ahead of the main output steps, to allow pre-triggering of the scope via its external trigger input.
- Both outputs are provided via SMA connectors.
- The adaptor is powered from 5V DC, which can be sourced from a USB port on a DSO, a PC or tablet, or a low-cost USB charger.
- Current drain is typically 16-20mA. A 3mm green LED provides indication that the generator/adaptor is operating.

Finally, Fig.11 shows the display when the 18m cable was deliberately mis-terminated with a 25Ω load at the far end. This causes a step down about 191ns from the start, with an amplitude that's very close to 1/3 that of the incident step. This is close to what you'd expect with a load impedance of Zo/2.

So these screen grabs should give you a good idea of what can be achieved. Happy cable testing!

By Nicholas Vinen

The Currawong Stereo 10W Valve Amplifier – Part 2

In Part 1 last month, we described the circuit and presentation of our new Currawong stereo valve amplifier. We now describe the PCB assembly and detail the timber plinth and chassis wiring, along with detailed instructions on putting it all together.

MOST OF THE parts for the Currawong are mounted on a single large PCB. This slides into a slot near the top of a timber plinth, with the remaining components – primarily the two large power transformers – underneath the PCB and attached to the plywood or MDF base.

The front panel carries the headphone socket, volume control, power switch and status LEDs. The input connectors, loudspeaker terminals and power socket are mounted on the rear panel, which is recessed into a cut-out in the rear of the plinth.

So let's start putting the main PCB together, which is a significant part of the work involved in building the Currawong.

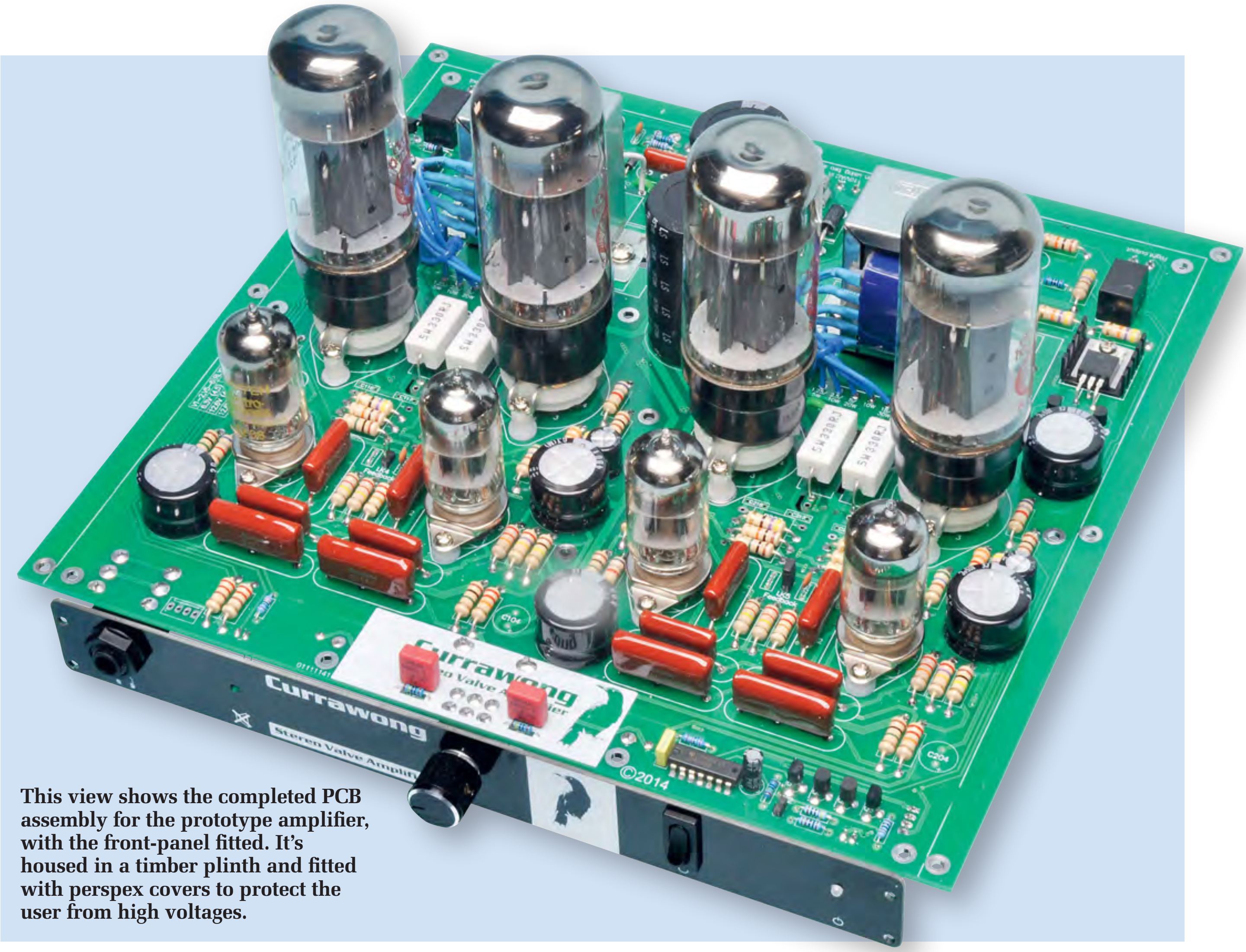
PCB assembly

Start the PCB assembly with reference to overlay diagram Fig.6. The board is available from the *EPE PCB Service*, coded 01111141 and measures 272 × 255mm. It's 2mm thick, which makes it more rigid and stronger than typical 1.6mm laminate.

Start by fitting the smaller resistors. The colour-coded stripes on small resistors aren't always distinct, so it's best to check each value with a DMM. Use the lead off-cuts to make the two wire links (next to LK4 and LK5).

Follow with the three 1N4007 diodes (D4-D6), in the top corners of the board, with the striped cathode ends towards the right or bottom of the PCB, as shown. IC1 can go in next – there's no need for a socket. Check that its pin 1 notch/dot is towards the left side of the board before soldering it.

Then fit all the 1W resistors. Their colour codes are usually clear, but it doesn't hurt to measure them to be



This view shows the completed PCB assembly for the prototype amplifier, with the front-panel fitted. It's housed in a timber plinth and fitted with perspex covers to protect the user from high voltages.

sure. None of these run hot, so they can be mounted in contact with the PCB. You may find it difficult to get the specified 9.1kΩ 1W resistors, so 8.2kΩ resistors can be used instead with only a minor impact on performance – **but don't use 10kΩ** – they may prejudice overall stability.

The two large 1N5408 power diodes are next, with both cathode stripes facing the bottom of the board. These will get a little warm, so we recommend spacing them about 5mm off the board (eg, using a 5mm-wide strip of cardboard as a temporary spacer). The W04 bridge rectifier can also go in now; again, it's a good idea to space it off the board a little.

Next, fit blue LEDs3-6. These have a dual purpose: to indicate the presence of HT and to illuminate the transformers. They also form part of the HT bleeder circuit, so they must not be left out (if you must omit them, use wire links in their place). Angle each one back so that it will shine on either T3 (LED5, LED6) or T4 (LED3, LED4) and make sure the longer anode leads go through the holes closer to the righthand side of the board.

Now you can mount all the TO-92 package small-signal transistors, ie, Q2-Q9. Don't get the three different types mixed up. Follow with the six fuse clips. Check that the fuse retention lugs are on the outside before soldering the clip in place, otherwise you will not be able to fit the fuses. Also make sure that they are pushed all the way down onto the PCB before soldering them in place.

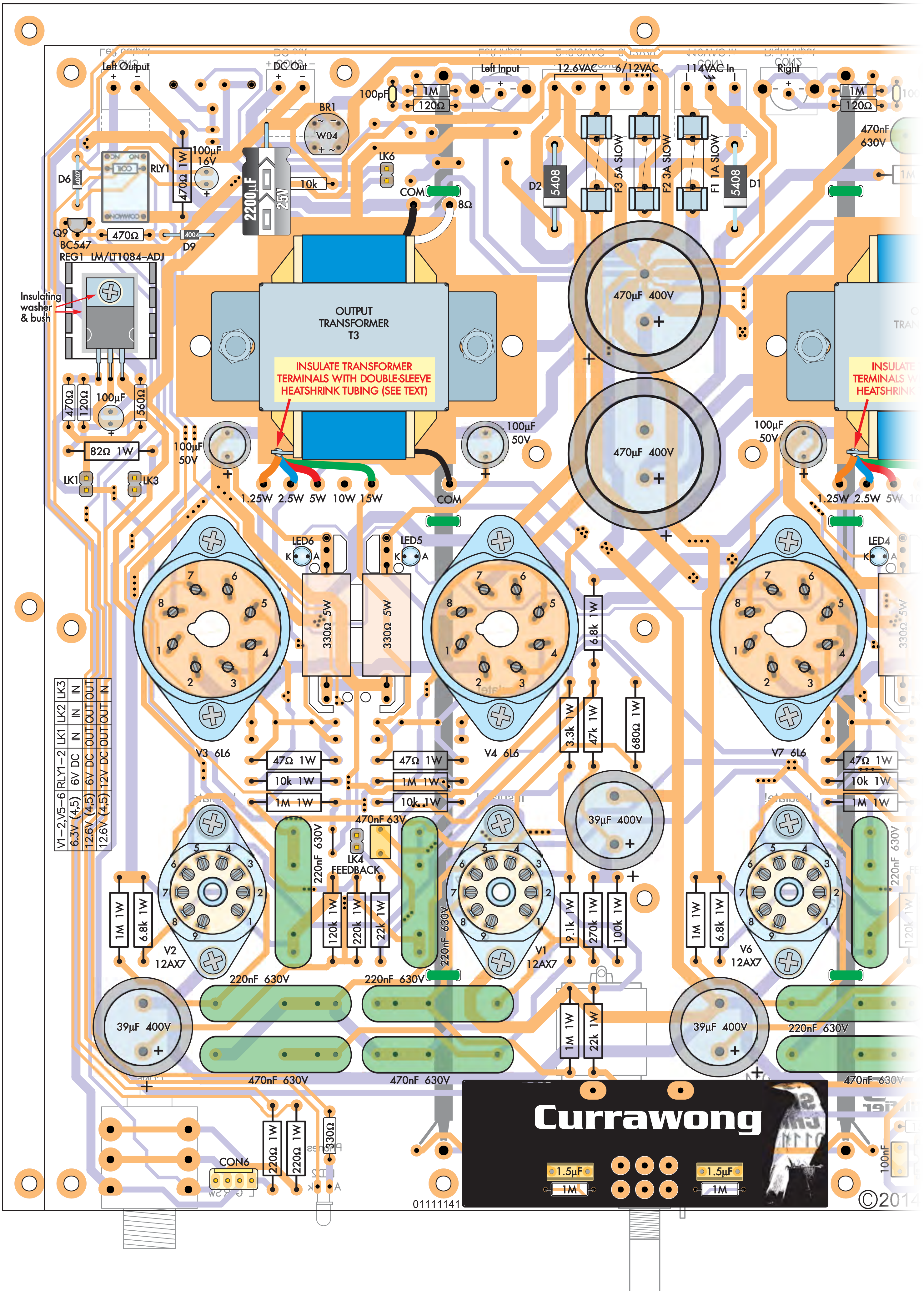
Next on the list are transistor Q1 and linear regulator REG1. These are both fitted with small heatsinks and it's important that the heatsinks are isolated

!!! WARNING – HIGH VOLTAGES !!!

High AC and DC voltages are present in this circuit. In particular, mains voltages (230V AC) are present on the IEC socket and the primary side of the mains transformers (including the wiring to the power switch). In addition, the transformer secondaries together provide a 114V AC output and the power supply produces an HT voltage in excess of 300V DC which is present on various parts of the amplifier circuit (including the output transformers).

Do not touch any part of the amplifier or power supply circuitry when power is applied – you could get a severe or even fatal electric shock.

The blue LEDs in the circuit indicate when high voltages are present. If they are lit, the power supply and various parts on the amplifier board are potentially dangerous. **To ensure safety, the completed amplifier must be fitted with perspex covers; described in Part 3 next month.**


Left Output
DC Out
100pF
1M
120Ω
Left Input
12.6VAC
6/12VAC
114VAC In
Right
BR1
W04
100µF 16V
RLY1
470Ω 1W
D6
2200µF 25V
10k
LK6
COM
8Ω
D2
5408
F3 5A SLOW
F2 3A SLOW
F1 1A SLOW
D1
470nF 630V
Q9
BC547
470Ω
D9
REG1 LM/LT1084-ADJ
Insulating washer & bush
OUTPUT TRANSFORMER T3
INSULATE TRANSFORMER TERMINALS WITH DOUBLE-SLEEVE HEATSHRINK TUBING (SEE TEXT)
470µF 400V
470Ω
120Ω
100µF
560Ω
82Ω 1W
100µF 50V
LK1
LK3
1.25W 2.5W 5W 10W 15W
COM
LED6
LED5
LED4
330Ω 5W
6.8k 1W
V3 6L6
V4 6L6
V7 6L6
3.3k 1W
47k 1W
680Ω 1W
47Ω 1W
10k 1W
1M 1W
470nF 63V
LK4 FEEDBACK
39µF 400V
220nF 630V
120k 1W
220k 1W
22k 1W
9.1k 1W
270k 1W
100k 1W
V2 12AX7
V1 12AX7
V6 12AX7
V1–2,V5–6 | RLY1–2 | LK1 | LK2 | LK3
6.3V (4,5) | 6V DC | IN | IN | IN
12.6V (4,5) | 6V DC | OUT | OUT | OUT
12.6V (4,5) | 12V DC | OUT | OUT | IN
CON6
220Ω 1W
330Ω
Currawong
1.5µF
1M
01111141
100nF
©2014

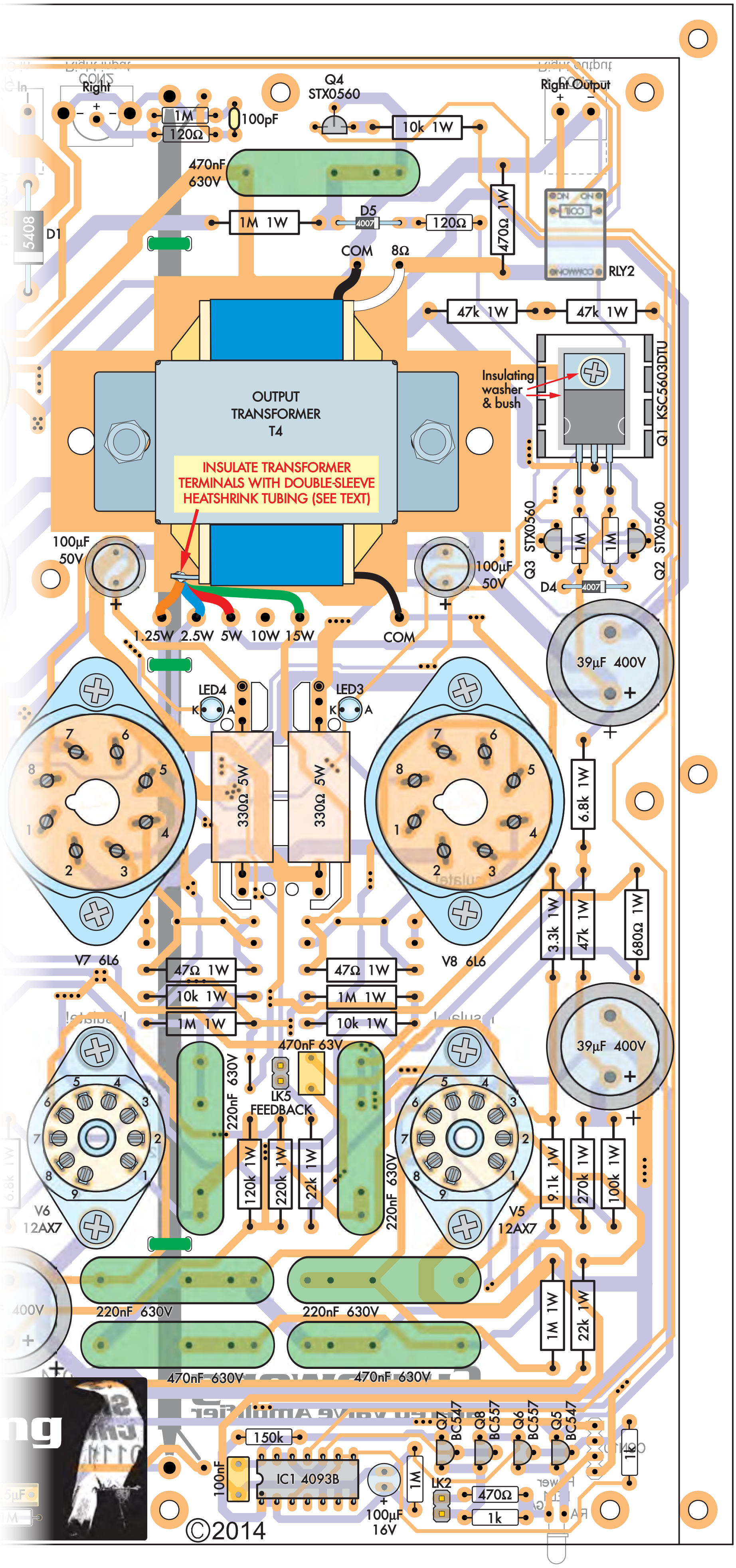


Fig.6: the parts layout on the top of the PCB. This diagram has been split and the righthand side partly duplicated where it meets the magazine gutter, for clarity. The text describes how the valve sockets are mounted; they must be mechanically secured before the pins are soldered. Note that D1, D2 and the 5W resistors should be stood off the board to allow air to circulate around them and don't forget to insulate Q1 and REG1 from their heatsinks.

from the device tabs using insulating washers and bushes – see Fig.7. In each case, start by bending the leads of the TO-220 device so they fit through the pads on the board, with the tab hole lined up with the PCB mounting hole.

Note that Q1's centre lead is bent closer to the package than the other two (due to the high voltage between the pins) but this is not the case for REG1.

To mount each device, place an insulating bush in the tab hole, then feed an M3 × 10mm machine screw through from the top. Slip an insulating washer under the device, over the screw thread, then slide the heatsink on from underneath. Drop this assembly onto the PCB, ensuring all pins go through their respective holes, then use a shakeproof washer and M3 nut to hold it in place.

In each case, ensure the heatsink and insulating washer are straight before tightening the nut fully, then solder the leads. That done, fit the two relays, making sure they are nice and flat on the PCB before soldering more than two pins.

Now it is time to install the ceramic capacitors, followed by the MKT (metallised polyester) capacitors, in increasing order of height. Follow with the six pin headers for LK1-LK6. Try to solder these flat on the board and neatly aligned with the edges of the board for best appearance.

You can then bend the leads of the four 5W resistors to fit through their mounting holes. There are two pairs of holes for each; we used the inner pair, but it isn't mandatory. As with the 1N5408 diodes, use a 5mm spacer to stand each resistor off the board. Keep them level and straight for a tidy result.

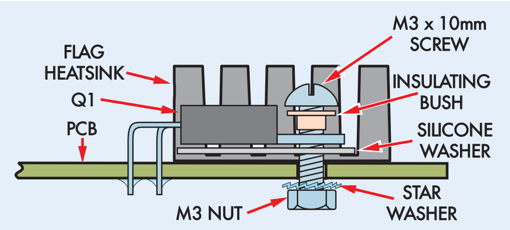


Fig.7: the mounting details for transistor Q1 and regulator REG1. In each case, the device tab must be isolated from the heatsink using a silicone insulating washer and insulating bush.

Parts List

Since publishing Part 1 last month, we've made a few small changes to the chassis arrangement and this affects the list of parts required. Please note the following changes:

Main board

(1) Delete vertical RCA sockets for CON1 and CON2; add short stereo RCA-RCA lead
(2) 2 × 8.2kΩ 1W resistors can be used instead of the 2 × 9.1kΩ 1W resistors listed

Revised chassis parts

1 timber plinth with base (see text)
1 top cover cut from 3mm clear acrylic (details to come)
1 small tube acrylic glue
1 front panel, available from the *EPE PCB Service*, code 01111142, 249 × 30mm
1 rear panel, available from the *EPE PCB Service*, code 01111143, 248 × 53mm
1 160VA 37+37+15+15V toroidal transformer
1 80VA 12+12V toroidal transformer (Altronics M5112)
4 screw-on 50mm equipment feet
1 15mm anodised aluminium knob to suit VR1
1 snap-in fused IEC mains male socket for 1.6mm panels
2 M205 250V AC 1A slow-blow fuses (one spare)
1 red chassis-mount RCA/RCA socket
1 white chassis-mount RCA/RCA socket
2 red binding posts
2 black binding posts
1 SPST ultra-mini rocker switch, 250V AC rated
1 1m length 2-core mains flex
1 1m length 3-core mains flex
1 200mm length 3mm diameter black heatshrink tubing
1 1m length 5mm diameter clear heatshrink tubing
1 200mm length 20mm diameter black heatshrink tubing
1 50mm length 50mm diameter black heatshrink tubing or large insulating boot
1 1m length heavy duty red hook-up wire
1 1m length heavy duty black hook-up wire
1 500mm length figure-8 speaker wire
1 12-way screw terminal strip
1 M4 × 10mm machine screw
2 M4 nuts and shakeproof washers
2 yellow 5.3mm ID eyelet crimp connectors
2 red 8.4mm ID eyelet crimp connectors
5 red 6.4mm insulated spade crimp connectors
4 solder lugs
1 5mm cable clamp (P-clamp)
12 black 4G ×12mm self-tapping screws
12 4G × 9mm self-tapping screws
1 4G × 6mm self-tapping screw
1 3mm ID flat washer
7 3mm ID spring washers
10 small nylon cable ties

The Currawong contains some hard-to-source components. A kit is available from **altronics.com.au** – code K5528, which is much the easiest way to assemble the parts. Readers who wish to buy parts individually should consider: **www.tandyonline.co.uk** for valves; **www.siliconchip.com.au/Shop/7/2877** for various items; and Altronics for the all-important specified transformers T1, T2.

The 630V polyester capacitors can then be fitted. The PCB is designed with multiple pads for each capacitor, to suit different lead spacings. If you have an odd one, you may need to bend its leads out – however, most should drop straight in. Refer to Fig.6 to see which type goes where.

Now solder the smaller electrolytic capacitors in place, ie, the six 100µF types. In each case, ensure that the longer (positive) lead goes in the pad closer to the front edge of the board, as shown on Fig.6.

Valve sockets

The valve sockets are secured to the board before soldering, so the solder joints aren't under stress. The specified sockets have solder lugs and the board has been designed with slots to accommodate them.

Start with the smaller 9-pin sockets. Feed M3 × 10mm machine screws

The 9-pin sockets are secured using M3 × 10mm machine screws, with a nylon nut and two nylon washers used as spacers at each mounting point.

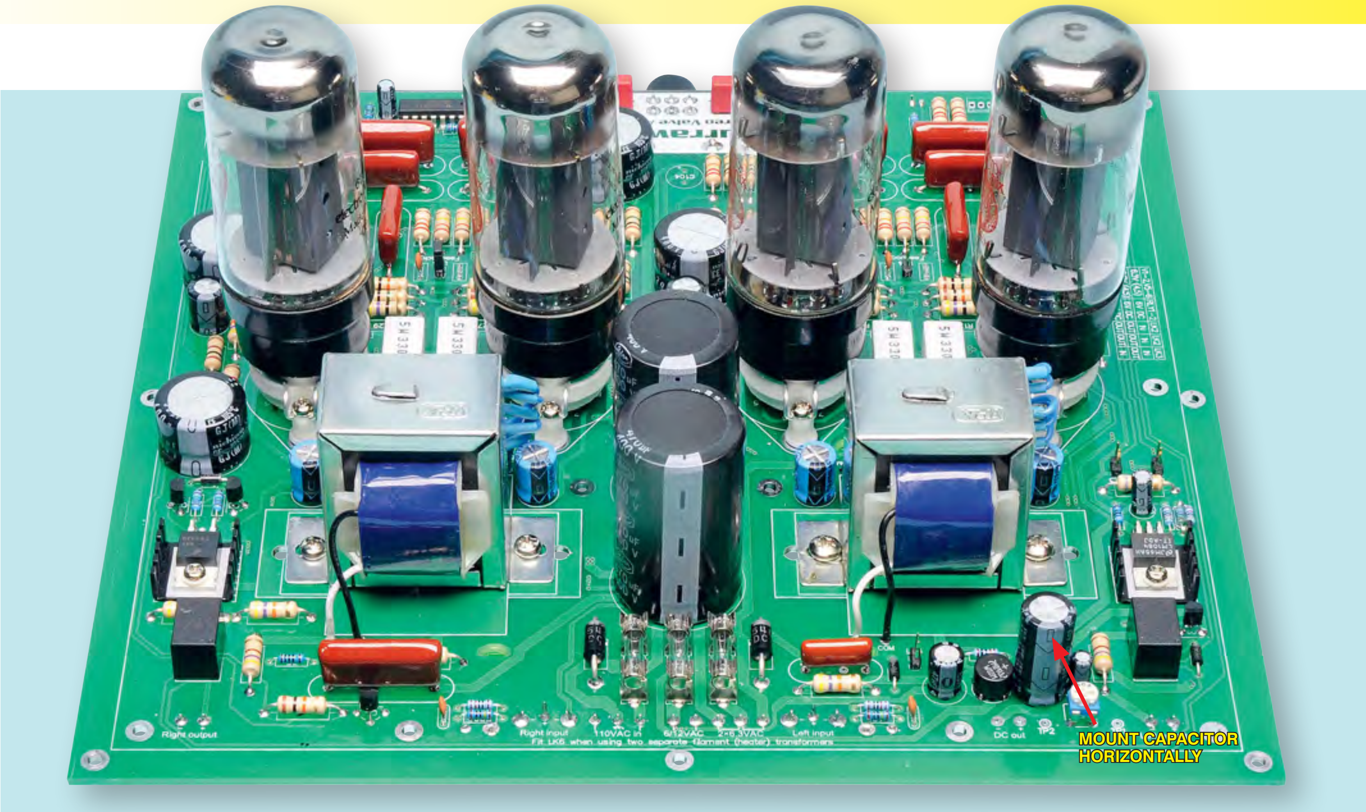
This mock-up shows the final mounting arrangement used for the 8-pin sockets (it differs slightly from that used on the prototype). These sockets are secured using M3 × 15mm screws and M3 × 6.3mm tapped nylon spacers.

through the top mounting holes and tighten nylon nuts on the underside. Slip two nylon washers over each screw thread, then pass the screws down through the mounting holes on the board, guiding the solder lugs through the slots. If it won't go in, check that you have the right orientation, as it will only fit one way.

You may need to put the solder lugs under a small amount of tension to get them to go through the slots, due to the way they are angled. But once they all line up it should slip into place and you can push the socket right down so it's sitting on the nylon washers.

Use a shakeproof washer and M3 nut to secure the screw closest to the front (bottom) edge of the board. **Fit a nylon washer and nut to the other (this is necessary to avoid shorts to adjacent PCB tracks) – see Fig.8.** Do both nuts up tightly, check that the socket is sitting level on the PCB and then solder the pins and repeat for the other three sockets. It isn't necessary to trim the solder lugs after soldering.

For the larger 8-pin sockets, the arrangement is similar but their mounting brackets are supplied separately. Take a bracket and feed M3 × 15mm



Another view of the completed PCB assembly, this time taken from the rear. Check the board carefully after assembly to ensure that all polarised parts are correctly oriented. Note that the 2200µF capacitor indicated by the red arrow must be mounted horizontally (ie, on its side) as shown in Fig.6, NOT vertically as shown here.

machine screws through the top of the mounting yokes (see photos), then loosely screw M3 × 6.3mm nylon tapped spacers on, just tightly enough so that the screws stay in place.

Now position this assembly over the PCB and adjust the spacing so that the two screws are equally far from the centre of the mounting bracket and they pass through the appropriate holes on the PCB. You can then remove the bracket and drop the socket in place. Some 'jockeying' may be required, but it should fit easily once you get all the pins lined up.

These sockets can be installed with eight different orientations but only one is correct. The notch in the central hole must face towards the lefthand side of the PCB. If you solder one incorrectly, it will be difficult, if not impossible to remove (see Fig.6).

With the socket pushed down onto the PCB and oriented correctly, slip the bracket on top and secure it in position with shakeproof washers and M3 nuts. **Note though that for valves V4 and V8, the mounting screw closest to the front (bottom) edge of the board must be secured with a nylon washer and nylon nut instead.**

Do both mounting nuts and screws up tightly, then re-check the socket orientation before soldering the eight lugs. Repeat for the other three sockets.

With all the sockets in place, fit the five low-profile 39µF 400V snap-in capacitors, again with their positive terminals towards the front (bottom) of the board. These should be pushed all the way down before soldering.

The 2200µF capacitor can now go in – however, it must be laid over towards transformer T3 or else the top cover will not fit later. There should be sufficient room for it to sit flat on its side on the PCB. Like the others, it is polarised and the negative stripe should face up.

You can then fit the two large 400V capacitors between T3 and T4. Double-check their orientation before soldering the leads and they too should sit right down on the board; if they aren't perfectly vertical, they may not later fit through their corresponding holes in the top cover.

Output transformers

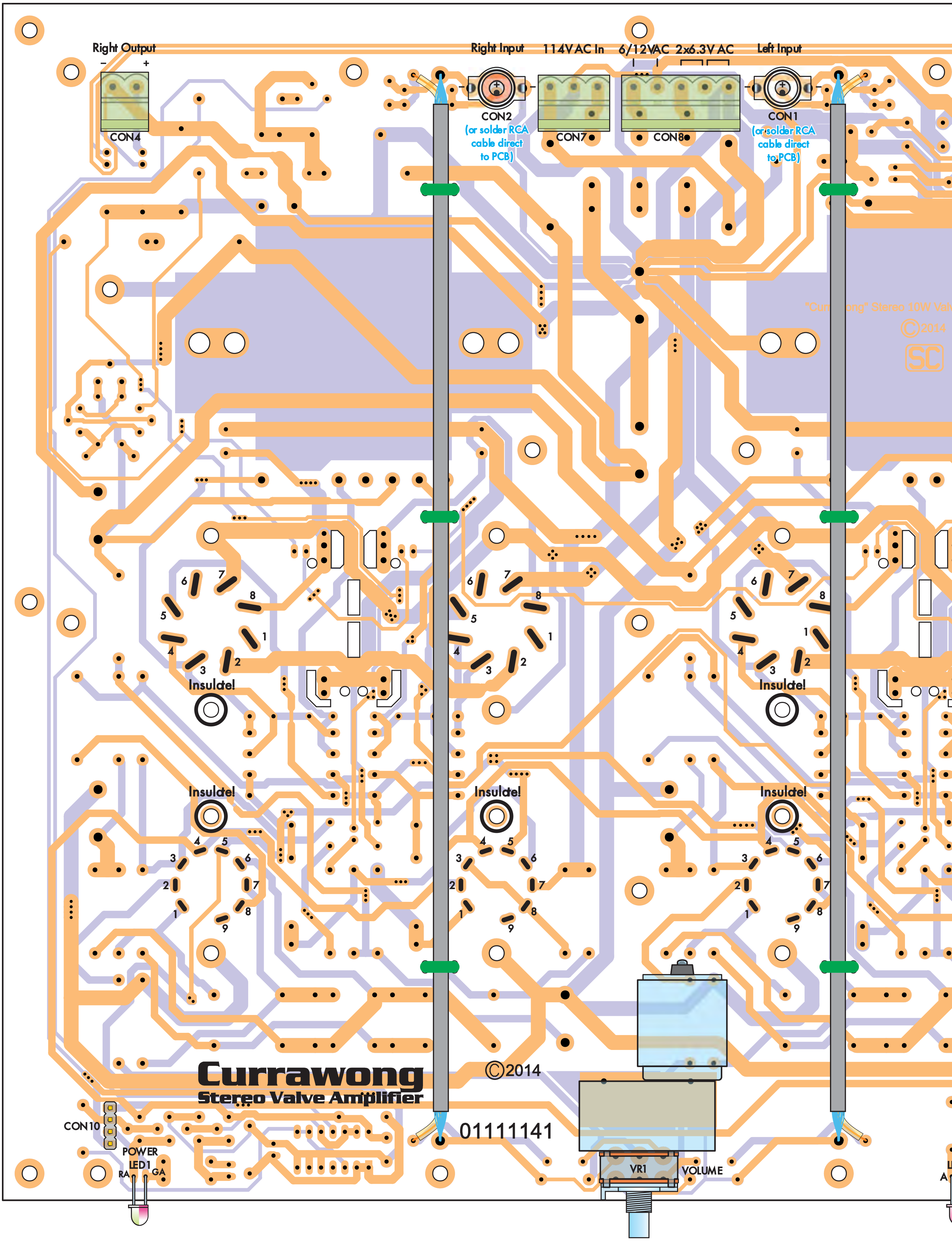
The 15W 100V line transformers (T3 and T4) come fitted with a terminal block on top and stickers indicating the taps. We removed these as we felt it improved the appearance. The stickers can be peeled off and the glue residue gently cleaned off using an appropriate solvent. Methylated spirits or isopropyl alcohol are good choices as they are unlikely to damage the transformer, but try not to soak it.

The terminal blocks can be simply pulled off, although they're a tight fit and you may need to use pliers. The metal tab used to hold it in place is then bent down.

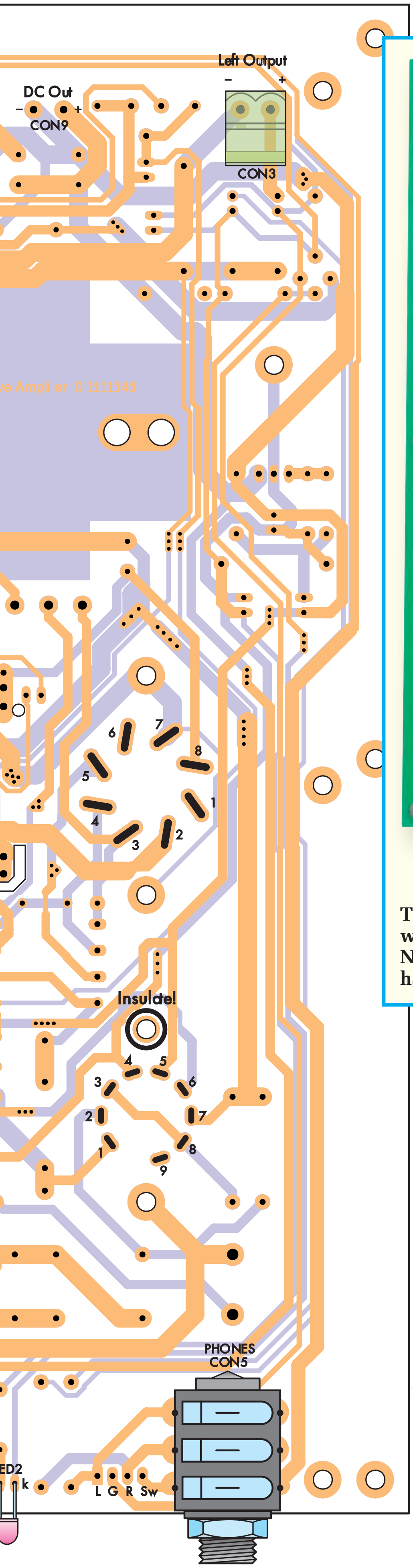
The next job is to cut, solder and insulate four or five wires to the winding tap lugs. The 10W winding is not connected on the PCB, so you don't have to wire it up – but we did anyway, because we thought it would look better. We used blue wire, to match the blue transformer insulation although different colours are shown on Fig.6 for clarity.

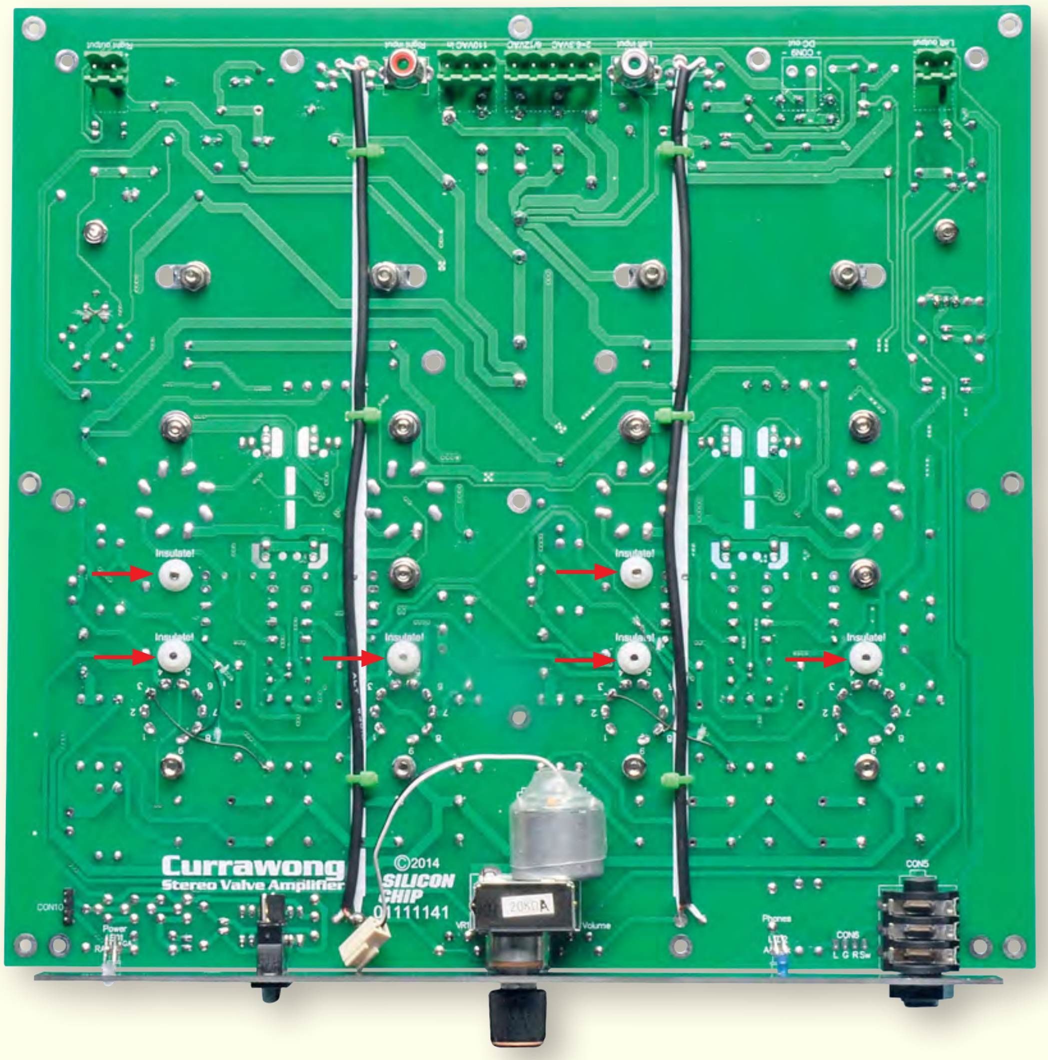
Cut each wire to a length of about 70mm, then strip about 3mm of insulation from one end and 6mm from the other. Feed the longer section of exposed wire through one of the solder lugs and double it over, then solder it in place. Try not to heat the joint more than necessary or add too much solder.

The output transformer terminals all operate at 308V DC and they must all be fully insulated with two layers of heatshrink sleeving to ensure safety. It's just a matter of slipping a 15mm-length of 3mm-diameter blue heatshrink tubing over each terminal and shrinking it down, then adding a second layer. **Make sure each terminal is fully insulated, including the 10W tap, even if you aren't soldering a wire to it. If necessary, use neutral cure silicone to ensure there is no gap**



Right Output
CON4
Right Input
CON2
(or solder RCA cable direct to PCB)
114VAC In
CON7
6/12VAC 2x6.3V AC
CON8
Left Input
CON1
(or solder RCA cable direct to PCB)
Insulate!
Insulate!
Insulate!
Insulate!
Currawong
Stereo Valve Amplifier
©2014
01111141
CON10
POWER LED1
RA
GA
VR1
VOLUME





This view shows the parts in position on the underside of the PCB. Note the nylon nuts and washers used to secure the valve sockets at various locations, as indicated by the red arrows. Note also that this is a prototype PCB and the short wire links on two of the 12AX7 valve sockets have been eliminated from the final version shown in Fig.8

in the insulation where each terminal goes into the transformer.

Twist the bare strands together at the other end of each wire and tin them in preparation for mounting. Do the same with the three pre-existing wires, after trimming them so that they will reach their PCB pads with a little slack. You can place the transformer temporarily on the board to check this. Don't cut the leads too short.

Once all the wires have been prepared, fit the transformers to the board

Fig.8: the parts layout on the underside of the PCB. A motorised pot is shown here for VR1, but a regular 16mm dual-gang log pot can be used instead if you don't want remote volume control. The RA/GA markings for LED1 indicate the position of the red LED anode and green LED anode respectively. Note the orientation of CON3, CON4, CON7 and CON8 and be sure to use nylon nuts and washers at the indicated 'insulate' positions when securing the valve sockets.

using M4 × 10mm machine screws, shakeproof washers and nuts. The front side (facing the bottom of the board) should have five or six connections, while the rear of the transformer has two. Make sure they are nice and square with the rear edge of the board, centred on their mounting positions and firmly secured.

It's then just a matter of soldering the eight wires to the PCB. The topmost of the five front wires goes to the leftmost pad, the next one down to the second-from-left and so on. Skip the pad labelled '10W' if you only soldered four wires. These can be tack-soldered initially from the top (without melting the wire insulation), then pushed through the board and soldered from the bottom afterwards.

Connect the three remaining wires as shown on Fig.6, then tie the bundles of four or five blue wires together using blue cable ties.

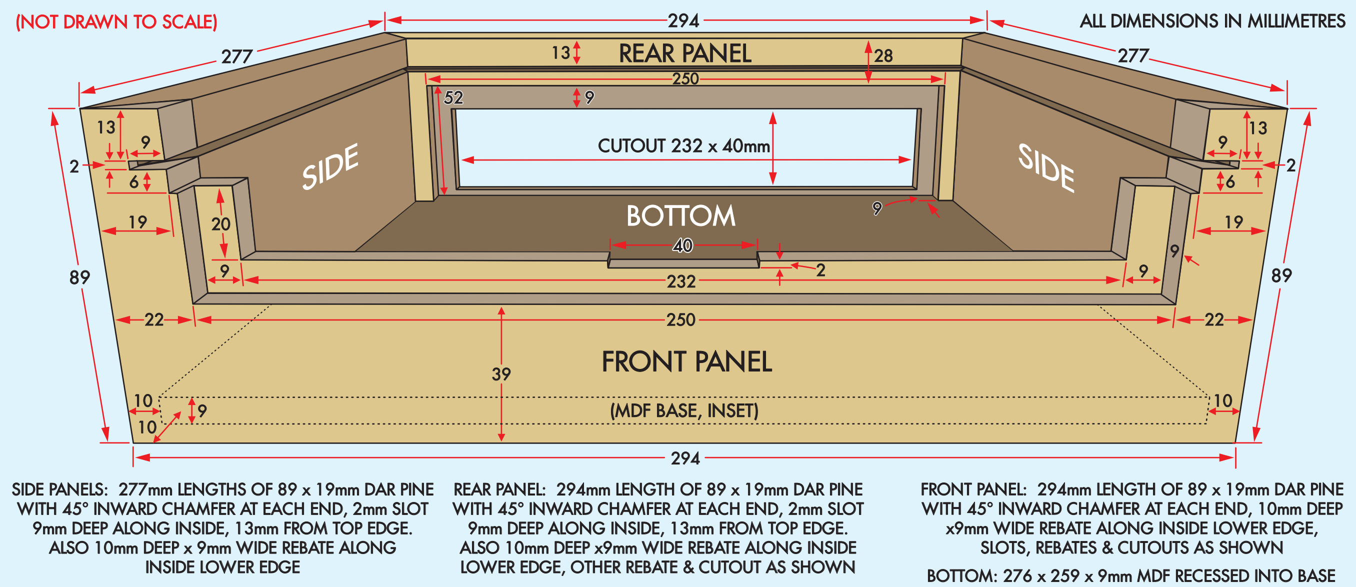


Fig.9: the Currawong plinth details. It's made from four lengths of 89 × 19mm DAR pine arranged in a rectangle with a 9mm MDF or plywood base. The slot cut into the sides and rear accommodates the 2mm-thick PCB while the cut-outs and rebates at the front and rear are for the two panels through which the controls and connectors pass.

Underside components

The remaining parts are fitted to the other side of the board, as shown on Fig.8. Start with the two shielded cables which run down the middle.

First, cut them to length and remove about 15mm of the outer insulation from either end, then twist the exposed shield braid wires together and strip about 5mm of the inner insulation away. Now twist together and tin these inner conductors and also tin the twisted end of the shield.

Solder the shield wires into the larger of the two holes at either end of the board and the inner wires into the smaller pads – see Fig.8. Make sure there's sufficient solder on the shield braid so that it's rigid and can't move and short to any adjacent pads. Also try to keep the wire reasonably taut along the bottom of the board. Once they've been soldered at each end, fit the six cable ties (three per wire) using the slots provided.

Next, fit the four pluggable terminal blocks. Make sure these go in the right way around, with the curved sections towards the back edge of the board (ie, towards the nearest edge).

The headphone socket can be mounted next and must be pushed all the way down onto the PCB. This can be followed by dual potentiometer VR1, after cutting its shaft to 15mm long. You can cut the potentiometer shaft using a hacksaw and then file off any burrs. If you've opted to have the remote volume control, solder the two mounting lugs for the motor in addition to the six for the pot itself.

Now for the two remaining LEDs: blue LED2 goes on the left (with the board right-side up) near the headphone socket, while bi-colour LED goes on the right. Use a DMM set on diode test mode to figure out which of the bi-colour LED leads is the red anode – the LED will light red when the red lead from the multimeter is connected to this pin (in our case, the longer of the two leads). This lead goes towards the righthand edge of the board.

Bend the LED's leads at right angles 7mm from its lens and fit the LED so that the lens is centred 10mm below the top of the PCB (ie, 8mm from the bottom). The other LED is fitted in the same manner, with its longer (anode) lead also towards the righthand edge of the PCB.

Input wiring

Note that while the board is designed to accept vertical RCA sockets for the input signals, we decided it was easier to solder a stereo RCA cable directly to the board, which plugs straight into the RCA/RCA sockets on the rear panel. This provides more clearance on the underside of the board for the transformers. So we suggest you get a short stereo RCA lead, chop off a ~500mm length, strip it back and solder it to the left and right input pads, with the shield braid to the terminals marked '–' and the inner conductor to '+'.

Now fit the three fuses; 1A for F1, 3A for F2 and 5A for F3 (all slow-blow). The main board assembly is now complete.

Building the plinth

The base of the plinth is a sheet of 5-ply or 9mm MDF cut to 276 × 259mm. The rest is made from a single length of 89 x 19mm dressed all-round (DAR) pine, cut to two lengths of 277mm for the sides and two lengths of 294mm for the front and back.

Fig.9 shows the plinth details. A plunge router is required to cut the rebates, and a mitre or drop saw is used to make 45° cuts so that the four pieces of DAR pine can be assembled in a similar manner to a picture frame. A drop saw is used to cut the 2mm-wide slots but make sure that all the slots will later line up correctly.

We used wood glue to hold it all together, along with 6G × 20mm wood screws to additionally secure the base. Once assembly is complete, check that the PCB will slide all the way back so that the front is flush with the front panel rebate.

After assembly, we smoothed the plinth using sandpaper, stained it with 'Jarrah' oil-based stain and finished it with a clear polyurethane lacquer.

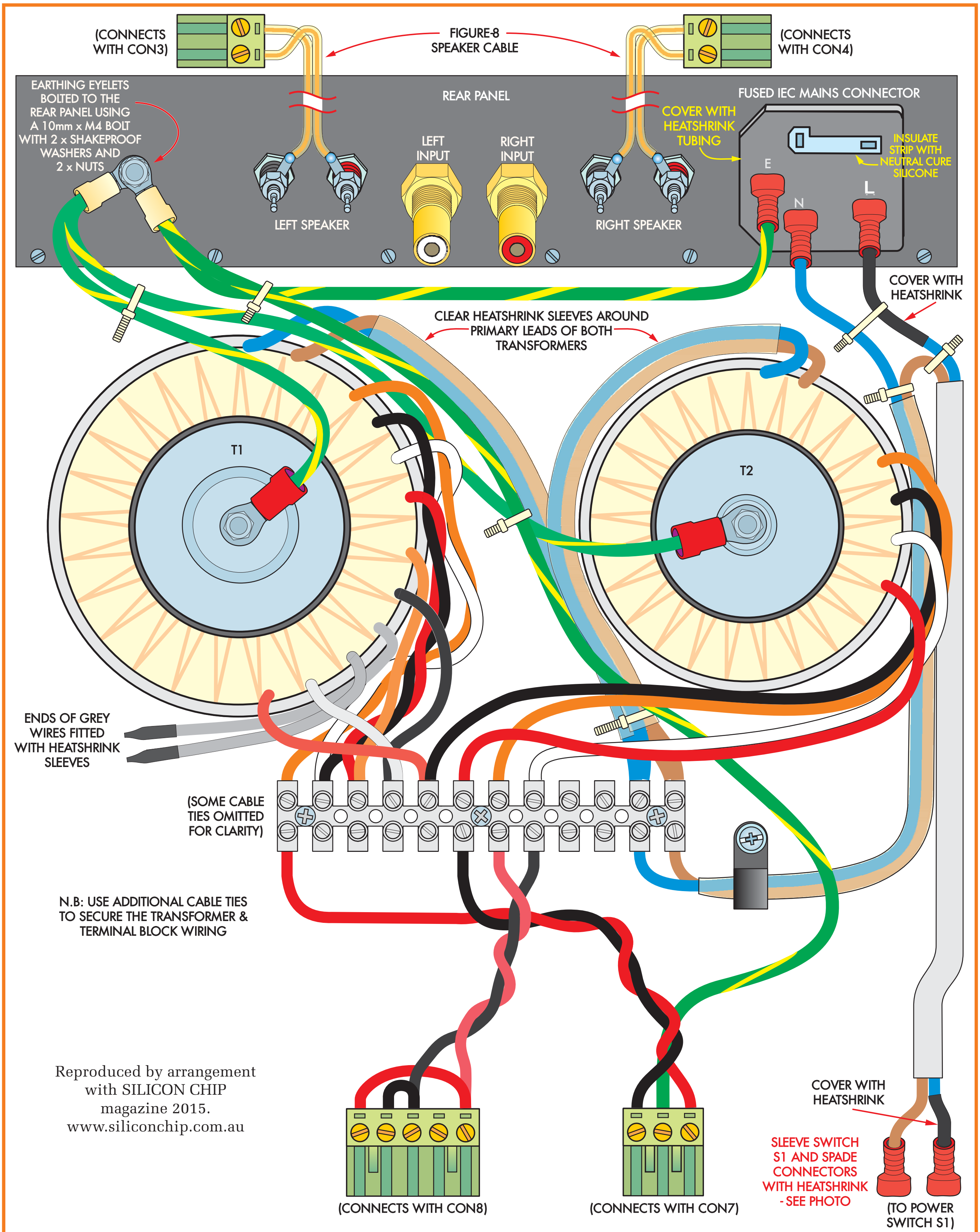


Fig.10: the Currawong wiring diagram. Besides the connectors on the rear panel and the power switch at the front, the only additional components in the case are the two toroidal power transformers (T1 and T2) and the terminal strip which is used to connect their secondaries to the main board. Be sure to pay close attention to the insulation and anchoring of all mains wiring and note that the IEC socket must be covered with heatshrink tubing (see photo).

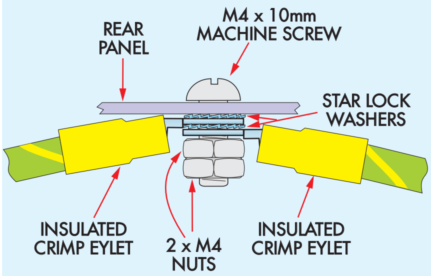


Fig.11: the earth leads are secured to the rear panel via insulated crimp eyelets as shown here. The second nut serves as a lock-nut, so that the assembly cannot come loose. Make sure that the leads are securely crimped.

Putting it all together

Start by fitting feet to the plinth. These should be placed just inside each corner and attached using 9mm 4G self-tapping screws. Drill a ~5mm-deep 2mm-diameter pilot hole for each foot before putting the screw in.

Next, fit the rear panel. This is held in place with a self-tapping screw in each corner and a few extras along the edge, primarily next to the mains input socket. You don't need to put screws through every single mounting hole provided. Again, drill 2mm pilot holes for each screw; due to the limited amount of space, you may need to use a pin vice.

Now fit the connectors to the rear panel. Fig.10 shows how the connectors are fitted. The IEC socket goes in with fuse towards the edge. It will snap into place and should not be able to move much once it's in.

The RCA connectors are supplied with two insulating washers; we kept the one on the inside but didn't bother with the one on the outside as the solder mask on the panel acts as an insulator. Do them up nice and tight; the profile of the mounting holes will stop them from rotating.

Similarly, the binding post mounting holes prevent them from rotating and should result in the wire hole through the metal shaft being aligned vertically. These should also be mounted securely, taking advantage of the supplied spring washers.

It's possible that some binding posts may have their wire hole misaligned, even though the shafts are keyed, so check before fitting them. If any are misaligned, you may be able to disassemble the binding post and reassemble it correctly.

Note that the wire holes on the specified binding posts are quite small. You don't need to use especially thick speaker wire with this amplifier due to the limited output power and low damping factor, but it would be possible to enlarge the mounting holes and fit bigger binding posts if necessary. Alternatively, use banana plugs, which plug into the end of the specified posts.

With the posts in place, prepare the two internal speaker leads. Cut some figure-8 cable to ~200mm lengths, strip about 6mm of insulation from both ends and split the two halves apart slightly at either end. Solder the wires at one end to the smaller eyelets of some solder lugs. Put these wires aside so they can be fitted later.

Power transformers

The transformers should be located as shown in the wiring diagram (Fig.10). Leave enough room between the transformers and rear panel so that you can later reach behind the main PCB as it's being slid in and plug the various connectors into the underside (this requires more clearance than is available above the transformers).

Note that T1 at left is the larger of the two (160VA). We suggest a gap of no less than 50mm between T1 and the rear of the case. In practice, this means positioning the transformer mounting bolts so that they are approximately 115mm from the back edge of the plinth (ie, about 96mm from the inside rear edge).

Mount the transformers using the supplied plastic mounting washers, metal plates and washers via 6mm holes drilled in the bottom of the plinth – do the nuts up loosely at this stage. Note that these mounting holes are the only ones drilled right through the base; all other screws used are self-tappers, which don't penetrate fully.

Now position the terminal block, as shown in Fig.10. Use three 12mm self-tapping screws to hold it in place; one in the middle and one at each end. Again, it's a good idea to drill 2mm pilot holes first.

For each pair of transformer primary wires (ie, blue and brown), cut a length of 5mm diameter clear heatshrink tubing to cover the entire length except for about 10mm at the end. Adjust the wires so that they run parallel and so that they end side-by-side, then shrink the tubing down. Bend the wires so they run as shown on the wiring diagram and terminate them in the terminal block. Once they're firmly screwed in placed, fit a cable tie around the lot.

The two grey wires from T1 aren't needed, so bend the bare ends over in a U-shape and then insulate with some 5mm diameter heatshrink tubing. Now, twist the six sets of transformer secondary wires together (red/black and white/orange). This will help to minimise the hum and buzz fields radiated by keeping the magnetic loops small. You can twist the grey wires in with their associated secondaries as we did, or leave them separate.

Now it's just a matter of bending the bundles of secondary wires down to reach the terminal block and screwing them in as shown in Fig.10. Be careful when doing the terminals up, since the solid copper wires are quite thin and are loose within their insulating sleeves. This makes it easy to think you've secured it in the terminal block when you haven't, so tug gently on each one to make sure it won't come loose.

Now make up two pairs of twisted red/black heavy-duty wires around 200mm in length and attach them to the near side of the terminal block, as shown in the wiring diagram. Screw the other ends into the plug portions of the pluggable terminal blocks as shown. Note the two extra short wires required for the 5-way plug; fit these now too.

Once all the wires are in place, measure the resistance between the red/black pairs in the two terminal block plugs (for CON7 and CON8). You should get a low reading (<10Ω). Any higher than that suggests at least one wire is not making good contact in the terminal block, so go over them again.

Earth wiring

Before making any connections to the IEC socket, it's a good idea to cover the exposed metal strip as this operates at 230V AC. We also shrunk a length of 50mm-diameter heatshrink tubing around the rear of the connector (Jaycar Cat. WH5582) – see photo.

Two earth wires are required. Start by stripping the yellow/green striped wire out of a length of mains flex, then remove the insulation from one end and crimp securely into a 6.4mm insulated female spade connector. Plug this into the IEC mains input socket and route the wire to the rear panel earth lug hole at the lefthand side.

Note that if you are using a plastic boot to insulate the mains socket, you will have to feed the earth wire through that before plugging it in.

This is the view inside the plinth with all the wiring completed. Be sure to cover the IEC socket with heatshrink tubing as shown.

Cut the wire so that it reaches 150-200mm beyond this earth lug hole, then mark the point where it passes that hole. Using sharp side-cutters, carefully remove about 25mm of insulation at the marked point without damaging the copper conductors. This can be done by making a series of nicks around the wire at either end of the 25mm section, to separate that piece of insulation from the rest, then slitting down the isolated section and peeling it away.

Double over the exposed copper wire, squeeze it together using pliers and then crimp it into one of the yellow 5mm-inside-diameter eyelet connectors. Bare the copper at the far end of the wire; this goes into the centre terminal of the 3-way pluggable terminal block.

Now for the second earth wire. This needs to reach from the top of one transformer mounting bolt, to the rear panel earth point and then to the other transformer mounting bolt. Cut it to length, mark the location of the rear earth panel point, strip the insulation at each end and crimp an 8mm-inside-diameter red eyelet connector at either end. Strip away the insulation in the middle as before and crimp it into the other yellow eyelet.

Now attach both yellow eyelets to the rear panel earth point as shown in Fig.11. To do this, feed an M4 × 10mm machine screw in from the rear and place a shakeproof washer over the thread, followed by the eyelet connector from the IEC socket, then another shakeproof washer, then the second eyelet and an M4 nut. Do this nut up tight, then another nut on top, so it can't possibly shake loose.

You can now remove the transformer mounting bolt nuts one at a time and fit the red eyelet connectors under the flat washers. When refitting the nuts, do them up firmly but not so tight as to risk crushing the transformer windings.

Switch wiring

Prepare the power switch by cutting a length of 2-core figure-8 mains flex to around 500mm, then strip away the outer insulation for about 200mm, exposing the blue and brown wires. Cut the blue wire short, to 40mm, then strip the end and cover it with 3mm-diameter bl ack heatshrink tubing back to the sheath. Crimp on a 6.4mm red insulated spade connector.

Cut the brown wire to the required length as shown in Fig.10 and strip the insulation at the end. Run this though a section of clear heatshrink along with the blue wire you cut off earlier and crimp a 6.4mm insulated red spade lug on the IEC socket end of the blue wire, as shown in the wiring diagram.

Now plug the two spade connectors into the rear of the IEC socket (blue wire to neutral, heatshrink-covered wire to live). If using a boot, feed them through first. Lay the cable along the bottom of the case and screw it into the terminal strip as shown. Fit the P-clamp in the position indicated using a 6mm self-tapping screw and washer after drilling a small pilot hole.

Preparing the front panel

If you're going to fit the optional remote volume control, you will need to drill a hole in the front panel for the

The rear panel carries the IEC socket, the speaker terminals, the audio input sockets and the earth screw. Do not operate the unit without the perspex covers in place (see Part 3 next month).

IR receiver. This should be vertically aligned with the power indicator LED (at right) and 28mm to the left. Drill the hole to at least 5mm.

Note that if using a pre-drilled IP front panel, there may be a hole position indicated on the rear but this may not be correct as we changed it while building our prototype.

The mains switch can now be fitted. It should click into place – but make sure it has the correct orientation, so that it's switched down to connect the two terminals. If your switch doesn't have an 'on' marking on the front, use a multimeter to check which way around it should go.

Now strip the sheath at the loose end of the mains twin flex back by about 30mm, strip the insulation from the two inner wires and crimp the two remaining 6.4mm insulated spade connectors onto these.

Slip a couple of lengths of 20mm diameter black heatshrink tubing over this cable and then plug the two spade connectors onto the power switch lugs securely. That done, slide one length of the heatshrink tubing right over the rear of the switch body and shrink it down, then slip the other length on top and shrink that too.

The rear of this switch must be thoroughly insulated (as explained above) since it is connected to mains live and is near the front panel controls and other circuitry.

Now fit the two speaker wires prepared earlier to the binding posts. This is simply done by securing the solder lugs between the two supplied nuts on each binding post shaft. Do this with the correct polarity, as shown in Fig.10.

You can finish all the wiring by fitting some cable ties. In addition to the one fitted to the transformer secondary wires earlier, use several others to tie the transformer secondary wires in bundles close to the terminal block so that none of them can come adrift. Also fit some cable ties to the mains and earth wiring to hold it in place.

Checking the wiring

Removing the board after it's fitted is a bit fiddly, so it's best to do as much checking as we can now. First, use a DMM set to ohms mode to measure the resistance between the earth pin on the IEC socket and each of the live and neutral pins. There should be no continuity at all (the meter should show 'OL' or similar).

Check also that there is no connection between any of the secondary winding connection points on the terminal block and any of the earth, neutral or live pins on the IEC socket. Then take a quick look over the wiring and make sure nothing is touching or shorting to anything it shouldn't be.

Move all the loose wiring (terminal plugs, etc) out of the way, then plug in an IEC mains lead. Check that the power switch insulation is intact, then plug in and switch on. Check the AC voltage across each pair of red and black wires connected to the terminal block plugs.

Use caution when doing this as the transformer secondaries can put out over 120V AC – don't touch the plugs while the power is on! It's easier to probe the terminal block where the red and black wires are terminated.

You should get close to 13V AC across the rightmost output pair (going to the 5-way plug). Now, if the transformer phasing is correct, the other pair (going to the 3-way terminal) will read over 110V AC; possibly over 120V AC with no load. If you get a reading closer to 90V AC then you will need to switch off and swap around the black and red wires from the 80VA toroid. Power it back up and check that the voltage is now correct.

If either reading is much lower than specified, there is probably a bad connection to the terminal block, so you will have to switch off and re-check all the connections. But assuming the voltages are OK, remove the IEC mains cord and proceed to final assembly.

Mounting the board

If you're fitting the remote volume control add-on (to be described next month), make sure that the remote board is attached to the main board and that the motor is plugged in. Then slide the board into the case carefully and slowly, checking that the connectors on the underside don't catch on any wires. Push it back about two-thirds of the way, with the attached RCA leads folded over the top, then plug them into the internal RCA sockets on the rear panel and push them all the way home.

It's a good idea now to check that there is good continuity between the inner and outer contacts of the rear panel RCA sockets and the input wire solder termination points on the top of the PCB. They should all read low resistance.

You must use a ratchet-driven crimping tool!

One essential item that's required to build this amplifier is a ratchet-driven crimping tool, necessary for crimping the fully-insulated quick-connect terminals to the leads.

Suitable crimping tools include the Altronics Cat. T1552, and the Jaycar TH1829. These all feature double-jaws so that the bared wire end and the lead insulation are crimped in a single action.

Don't even think of using one of the cheap (non-ratchet) crimpers that are typically supplied in automotive crimp kits. They are not up to the job for a project like this, as the amount of pressure that's applied to the crimp connectors will vary all over the place. This will result in unreliable and unsafe connections, especially at the mains switch and IEC socket terminals.

By contrast, a ratchet-driven crimping tool applies a preset amount of pressure to ensure consistent, reliable connections.

Now for the tricky bit. It's necessary to plug the four terminal blocks into the underside of the board, but you have to slide it almost all the way back for there to be enough clearance underneath to do so. Thus, you need to reach around the back edge of the board and push them up into place. And watch out because unfortunately, these pluggable connectors are open on the sides so it's possible to plug them in offset from the correct position!

Start with the 3-way and 5-way connectors in the middle of the board as these will have the best clearance and you won't have to push the board back as far to plug them in. Note that the screw housing projection of each plug faces the front of the case.

Once they're in, you can check that the 3-way connector is fitted correctly by confirming good continuity between one of the valve socket mounting screws and the IEC socket earth pin. Similarly, the 5-way connector is plugged in correctly when there is a very low resistance between the pins at either end, which you can probe on the top of the board.

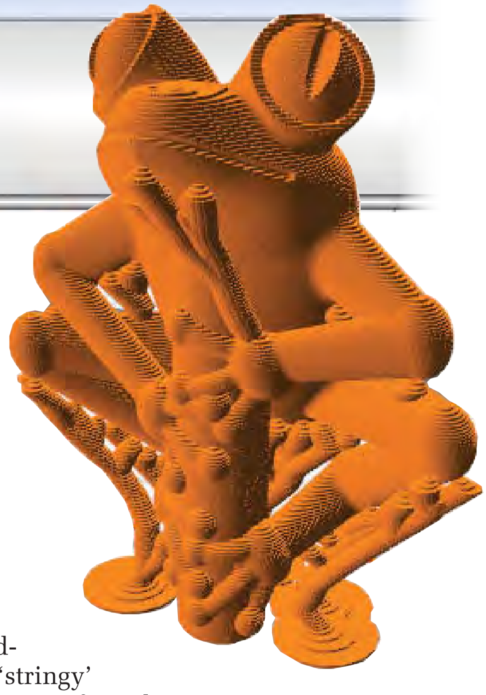
This metal strip on the IEC socket operates at 230V AC and should be insulated using silicone sealant.

The procedure for the two speaker terminal plugs is the same, but you will probably have to push the board back even further to make room for them to fit. Check for good continuity between each '+' speaker output pin on the top of the board and the red binding post.

Assuming that's all OK, push the PCB all the way back. You may find it hesitates when it reaches the rear panel but you should be able to 'finagle' it in. Recheck the isolation between the earth and live/neutral pins on the mains socket, and the live/neutral pins and the eight supply pads on the main board (ie, immediately behind the fuses), just to make sure that pushing the board in hasn't disturbed any of the wiring.

Now place the front panel over the pot shaft and gently push it back, guiding the two LEDs through their respective holes. Loosely fit the pot and headphone socket nuts, then you can drill 2mm pilot holes for the two lower mounting holes in the corners of the panel and attach it using two black self-tapping screws. Finish off by tightening the two nuts and attaching the knob.

That's all we have space for in this article. **Next month, we'll go over powering it up and checking it out. Then we'll fit the clear top cover, to make the whole thing safe to operate.** We'll also describe the optional remote control add-on board.



REVIEW BY ALAN WINSTANLEY

Many ideas start life as industrial or scientific concepts before finding their way to the consumer market, and one of the most exciting and intriguing developments in recent years has been in the field of 3D printing. Three-dimensional prototyping has been fuelled by the needs of industry, and so-called 'rapid prototype development' enables computer-aided designs to be transformed into solid objects fused out of metal or plastic particles, or carved from layers of paper or plastic using some exotic high-end automated equipment. Big names such as HP are said to be 'all over 3D printing', gearing up to offer commercial 3D printers and services as technologies improve. Next year, America's GE Aviation and France's SNECMA will start 3D printing of some impossibly designed fuel nozzles for jet engines that can only be fabricated with a laser-powered direct metal additive printing process.

As far as the everyday home user is concerned, 3D printing has been something of an emerging and temperamental process best left to experimenters and enthusiasts. As far back as December 2009, *EPE* reviewed the Rapman 3D printer for hobbyists, which showed the way things were heading, but the concept of 3D printing had yet to gain mainstream traction.

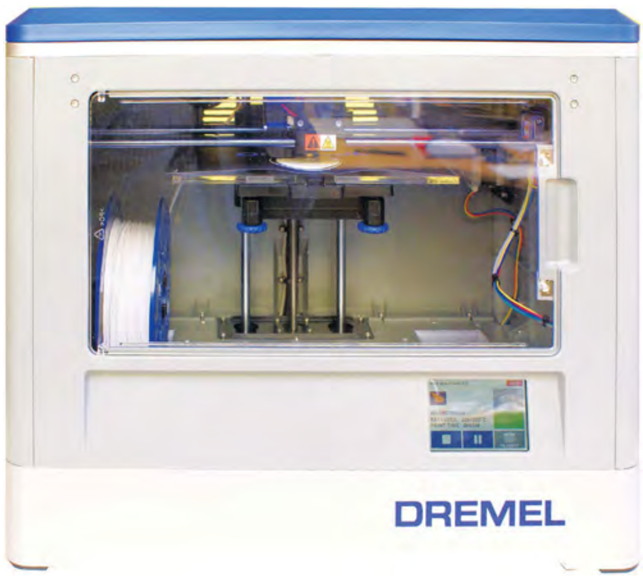
Things could be about to change as the technology is refined and new printers are released destined for the mass consumer market. In this special *EPE* review we look at a new arrival on the UK 3D printing market offered by a familiar tool brand that's targeted squarely at the everyday home user. Before taking it for a test run, let's consider some general practicalities of 3D printing.

More recently it's become feasible for the home constructor to fabricate even quite complex 3D shapes successfully, thanks to the latest crop of 3D printing machines. These all work by extruding and 'printing' or depositing layers of hot plastic in the same way that toothpaste is squirted from a tube. A typical 3D printer automatically builds shapes from the ground up, layer upon layer, using three stepper motors in the X, Y and Z axes to steer a hot extruder head in any direction, depositing a hairline stream of molten plastic as it goes along. The resultant bead of polymer is laid onto a bed or platform where it solidifies almost instantly. The platform lowers and more molten filament is then laid on top of that, where it fuses onto the layer of plastic underneath – hence the term fused-deposition modelling (FDM), which we will focus on here.

Mass production

Layers can also be printed in 'mid-air', exploiting the 'stringy' and fast-setting properties of molten plastic to build bridges as it goes along. Think of sticking things together with a stringy glue like UHU and you'll get the idea. Rather than producing solid plastic objects, which could take forever and consume wasteful volumes of material, objects can have an air-spaced lattice interior that saves on plastic while maintaining a useful degree of strength. Gradually, an object builds up in a process that can take anything from 20 minutes to several tens of hours depending on the scale of the design. Like choosing to print a photo in draft or fine mode, the 3D resolution can be set to balance print speed against the need for fine detail.

The end-results can be impressive, and 3D-printed objects can be surprisingly strong and durable. During printing, several variables can affect quality and performance overall, which can make the difference between success or failure, so experimentation comes as part of the package. First, the object must obviously remain perfectly still at all times, so that layers register on top of



The Dremel 3D20 is an enclosed, single-filament PLA printer for home users, students and beginners in 3D printing

each other with accuracy. Getting the object to tack itself onto the 'build platform' during printing is a key factor. Various workarounds can help with reliability, including (on some machines) heating up the build platform, or printing onto textured masking tape or Kapton tape, or applying home-brewed adhesive sprays to help ensure the object doesn't slide around – but hopefully not so much that it can't be removed without damaging it afterwards!

An object with a decent 'footprint' will probably remain stable on the platform than a more intricate one that might come adrift. The only way to know is to try it. Designs that might prove difficult or impossible to print include those with substantial overhangs or tiny footprints – eg, an upside-down pyramid or something with long branches that might benefit from extra supports, which can be added to some designs to prevent them from collapsing or toppling over during printing. That is a matter for the more ambitious designer/user to consider, but 3D printer users will start to appreciate such factors as their confidence grows.

The process is quite finely tuned, and other factors to consider include the ambient air temperature or airflow. Some machines have an open construction and some are fully enclosed and ventilated, so grilles and fans are sometimes used to tweak the printing environment. Other variables include the extruder's operating temperature and feed rate. Default values are usually fine, but five or ten degrees either way might make all the difference.

Material gains

The main point is that successful 3D printing has a gentle but highly rewarding learning curve. Sometimes it takes a little sympathy and understanding of what's happening to the molten plastic and how to harness it (or compensate for any minor hiccups), to ensure 3D printing is successful. Hence 3D printing originally appealed more to a dedicated hobbyist and has not been sold as an 'out of the box' concept for the everyday home user – until now that is.

3D-printed objects that look like smooth, 100% commercially made, mass-produced injection mouldings (like those made by some 450-tonne machines I have worked with!) won't be obtained, but 3D printing will produce the next best thing and the experience of seeing something gradually materialising out of thin air is a magical and often mesmerising one, better than any screensaver, especially if you designed the object on-screen yourself.

Several thermoplastics are readily available for 3D printing and some polymers are more demanding to use than others. They are commonly 1.75mm or sometimes 3.00mm diameter, supplied on reels that are force-fed through the hot extruder. ABS (acrylonitrile butadiene styrene) is common in injection-moulded electronics enclosures, computer mouldings and equipment housings. It's quite robust and shatterproof, but ABS filament is better used on higher-end 3D printing machines. Pitfalls include the irritating fumes produced when moulding ABS, along with the slightly higher temperatures needed. A heated platform is strongly recommended to print ABS objects on, so ABS printing is probably best left for the dedicated hobbyist who might also experiment with carbon fibre-filled or conductive filaments that are still in their infancy.

Polylactic acid (PLA) filament is the main alternative to ABS, and it has several benefits including lower melting points and being virtually odour-free. PLA is also biodegradable and non-toxic. Less easy to obtain is rubberised PLA filament for printing flexible parts like model tyres, and (can you believe) glow-in-the dark PLA, but the variety of materials is bound to improve over time. Unless you are a serious hobbyist, PLA is likely to be the best choice for home users.

The Dremel 3D Idea Builder uses polylactic acid (PLA) filament, which melts at a relatively low temperature and is virtually odour-free – ten colours are available from Dremel. A 0.5kg reel holds 190m of filament

Dremel 3D Idea Builder

As a sign of things to come in home 3D printing, the hobbyist tool manufacturer Dremel, the brand now owned by Bosch and best known for its precision mini power drills and tools, has thrown down the gauntlet with the launch of the 'Dremel 3D Idea Builder' that arrived in the UK recently.

This computer-aided tool is quite some departure for Dremel, who admit that it had a lot to learn about this type of technology. Its new 3D printer is a complete package that is aimed fairly and squarely at the home and family user, rather than just the workshop hobbyist or maker.

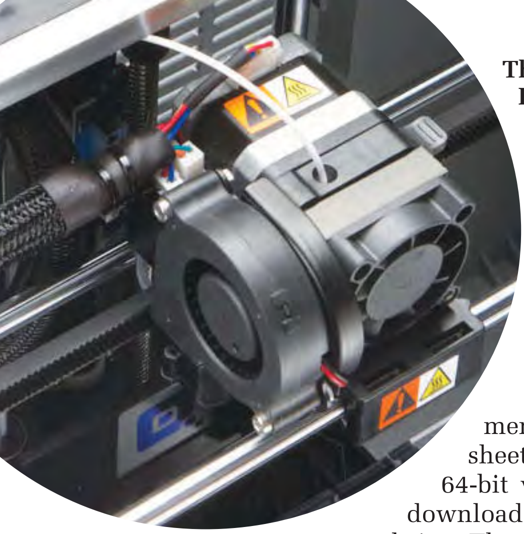
Dremel's 3D Idea Builder is a bold attempt to mass-market a 3D printer as a fully sorted, consumer product that works right out of the box. I was keen to see whether 3D printing had finally become an everyday, family friendly experience for ordinary home users, and a demo unit duly arrived from Bosch for trials.

I was immediately struck by the completeness of everything, from the packaging to the software and the web resources that a Bosch-backed giant like Dremel can put together effortlessly. The fully branded documentation and display packaging are as good as they get: material seemed to be very user-friendly and aimed at family and non-expert, everyday users. A *Quick-start Guide* hints of an easy set-up as if buying a new Hi-Fi or TV. A printed glossary was also welcome, just the thing for 'newbies' itching to start 3D printing. Dremel has done a thorough job of presenting an inspirational machine and new buyers will be eager to plug it in and get cracking.

The display carton unfurls to reveal the printer, a fully-enclosed machine roughly the size of a microwave oven. A simple drop-on plastic lid exposes the accessories bundle – an SD memory card, a scraper for prying 3D models off the printing platform, a wire unclogger tool, and USB and power cords. The extruder head and build platform nestle in an elaborate styrene packing piece, securing the motorised mechanisms in transit.

The printer head and build platform can then be accessed, with linear bearings and worm drives, stepper motors and toothed belts evident everywhere, plus some miniature microswitches dotted around to detect the end of travel. After unboxing, some mechanical sympathy is needed to raise the build platform manually to its upper limit, before removing more packing to find a vacuum-packed spool of white PLA filament bundled inside the printer. First impressions of this purposeful-looking printer are excellent, but how does Dremel's new 3D Idea Builder fare in practice?

This 3D printer can run as a self-contained standalone printer, using design files loaded on the SD card (32GB maximum) or stored in 4GB of non-volatile internal memory, or it can connect to a host computer via USB. It needs Windows Vista (32- or 64-bit versions) or higher, but the printer also works with Mac (OSX 10.8+). Not



The printer head of Dremel's 3D Idea Builder, mounted on precision linear bearings and driven by worm drives, stepper motors and toothed belts – visible are the filament entry point and active cooling fan

mentioned in the spec sheet is the Ubuntu (32- or 64-bit versions) driver also downloadable from Dremel's website. The Dremel 3D desktop software and some ready-to-print files are provided on the SD card. Plenty more designs can be downloaded from the web, and standard `.STL` design files can also be converted with Dremel 3D to drive the printer. It calls for a `.G3DREM` file format, which means that not every 3D program can drive the Dremel 3D idea Builder directly. For fun, the software lets you strip layers back one at a time so you can see how the object will build up.

After opening the software, it claimed to have somehow downloaded a firmware update and I also installed a later version of Dremel 3D on my Windows 7 PC. Finally, the printer was connected via USB and powered up, playing a tune on start-up. Some fan noise is noticeable (think of noisy laser printers), a bar of LEDs illuminates the interior and its colour can be changed or dimmed via the desktop software. The printer's 3.5-inch IPS touch-screen LCD is bright and very clear, and it opens with simple Build and Tools options. The touch-screen works very well and the menus are largely self-explanatory and simple to navigate – nothing intimidating here.

Looking inside, expressing its unashamedly PLA-only credentials, the Dremel 3D Idea Builder has an unheated build platform made of acrylic. Hence objects must always be printed onto 'build tape', not directly onto the acrylic platform, which will be ruined otherwise. Dremel includes several build tapes that are thin, matt plastic sheets with a 'grippy' PVC-type reverse. Its non-slip clingy backing aims to secure the build tape onto the acrylic bed, while the matt surface is designed to stop objects from dislodging themselves and causing the print to fail. In turn, hot plastic is intended to (only) tack itself onto the built tape but still be removable after printing.

Loading up

The spool of 1.75mm white PLA can be installed after powering down. It is vacuum packed and is best opened only when ready for use, to prevent degradation. The supplied spool holds 190m and a scale shows the length remaining. The maximum build volume is 230 × 150 × 140mm and the acrylic build platform clicks into the machine very positively, but it's easy to remove it once printing has finished.

Powering up again, filament is loaded or unloaded via the LCD's Tools menu. (The head can also be preheated via the same menu.) The extruder head heats to the default of 220°C and then filament is placed into the extruder top where it is grabbed and fed in. After about five seconds – success! – a rewarding little rivulet of molten plastic emerged underneath, solidifying instantly. An active cooling fan is also on-board, designed to prevent printed objects from warping.

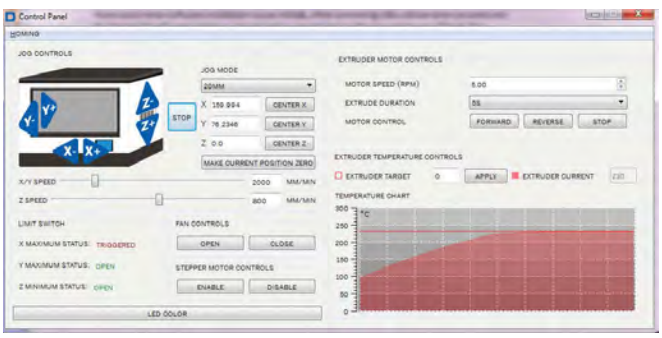
Accurate levelling is important – the clearance is set manually using a 0.3mm plastic shim, which is supplied

Once the build platform is installed again, it needs levelling accurately and a Tools menu option causes the build platform and extruder head to come together. The clearance is set manually using a 0.3mm plastic shim supplied. Some knobs underneath the platform are turned to set the gap at the left, right and rear, and also to adjust the levelling – the LCD was commendably clear with instructions. The printer was then ready to tackle its first job.

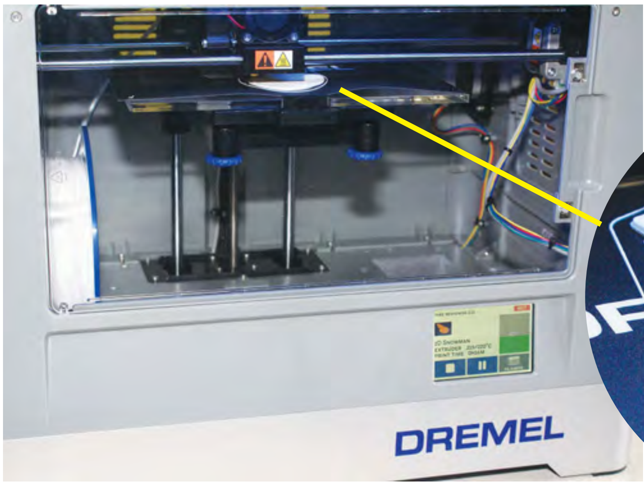
The supplied Dremel 3D desktop software, which handles the *printing* of objects, not the *design* of them, offers some basic functions including view, move, rotate and scale. If the object is too large to print, it turns red on-screen. Right-clicking pops up dialogue boxes for entering measurements or co-ordinates manually if desired, rather than dragging the object with a mouse. The software was generally well organised and unintimidating to use. A software control panel in Tools monitors temperature set points with a graph and other functions, for more advanced users.

For my first 3D printing project I chose a simple 2D design downloaded from the Dremel website. With winter fast approaching, what better than a 2D snowman, I thought, and the print file `snowman.g3drem` was duly fetched and opened in Dremel 3D. With the printer online I scaled the design and clicked BUILD (CTRL+P also works): the program estimated a 20 minutes build time using 3.33m of filament and the job was uploaded to the 3D printer over USB. As mentioned earlier, the quality of results can be altered to improve details, and the printer boasts a resolution of 100 to 300μm (microns), or 0.1 to 0.3mm per layer.

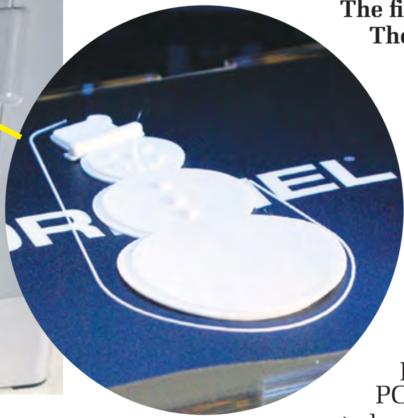
The printer LCD shows the job's progress, current temperature and time needed, and printing commences by laying down the first layer. I agree with Dremel that these early stages are the critical ones, because if the bead tacks itself to the build tape properly (success!) then it is a fairly safe bet that the whole job will probably complete without a hitch, otherwise any minor snags are likely to be seen at this initial stage of printing.



Control Panel software has temperature settings, LED colour control and more



A print job under way – the touch-screen shows progress and printing can be paused



The first completed job removed from the printer. The build tape warped slightly in this early test

Mad science

The Dremel 3D Idea Builder printed out the flat snowman shape, finishing off with a pointy carrot for a snowman's nose. There was little if any odour from the printer. However, the object was slightly skewed as the build tape underneath had warped slightly. Maybe it was not seated properly and had shifted, but it was a factor that might need regular attention.

A file from the included SD card was loaded next, the printer LCD showing a thumbnail of each project. A tree frog model was attempted but a foot got knocked out the way after ten minutes so the print was aborted. On a second attempt, the whole body got nudged out of the way as it slipped on the build tape. Still climbing the early learning curve, I suspected the tape was still insecure so it was re-seated and wiped with isopropanol to be sure, and another sample was successfully printed.

A model of a 'mad scientist' downloaded from Dremel also failed to print initially as it dislodged from the builder tape halfway through. Undeterred, I re-seated the build tape as advised, pressing it down very firmly onto the acrylic bed and happily several more models were built successfully, including the 2D snowman, as confidence grew. A downloaded Minion character came adrift, its two small feet insufficient to stick the mass down fully, so designing such things on a small plinth would be a much safer bet. Clearly, the size of an object's footprint affected how well it stuck down on the unheated platform during printing.

The printer could generally be left alone to get on with its job, with some 'babysitting' confirming the filament was unreeling freely and the object was seated properly. The print job can also be paused and resumed on-screen or via the PC software if needed. Also, it's essential not to bump or knock the machine during printing, especially for jobs taking many hours to print.

Unfortunately, I hit a snag on day two after powering up the machine ready for more trials – no hot plastic was being extruded at all. The procedure to unclog the nozzle was followed repeatedly, which involved poking the wire tool to force residual molten plastic through the extruder nozzle. A small amount ran out as expected, and the filament was reloaded again, but it still would not feed properly.

Dremel suggested the (cold) nozzle should be unscrewed using a hex wrench. A small piece of cold filament did indeed fall out, which looked the likely culprit but unfortunately the feed was still jammed with, I suspect, an errant piece of PLA.

Not wishing to take the extruder mechanism apart to clear it, a replacement machine arrived next day, which I'm happy to report performed flawlessly and I could not reproduce the earlier problem at all, despite my best efforts. Numerous attempts and loading and reloading filament went perfectly. I ran the replacement machine tirelessly and a multitude of objects starting with a 6-sided die were printed without a hitch. The 'mad scientist' was revisited, this time scaled up to 80mm height, which printed perfectly. One object, a prism shape, sagged at one end when the first few layers were being deposited. Most impressive was a 3D head of a T. Rex dinosaur,

T. Rex printed in remarkable detail

The demo tree frog printed successfully once the build tape had been secured. The 'footprint' can affect initial adhesion to the build tape, so be prepared to experiment

Models can be scaled up in Dremel 3D to print larger copies (Dremel Mad Scientist)

A cubic die was printed – note the lattice interior fill

which demonstrated how convoluted hollow shapes could be printed successfully. A set of modeller's needle files would tidy up the finish if needed.

As my army of tree frogs will agree, some objects print better than others; as a matter of course you get a feeling for what works well and what does not, but any nagging doubts are soon left behind as you start to use the printer with confidence. I found that getting the job to start properly on the build tape was the main factor, and objects with a good solid footprint were completely problem-free. In fact, on the second machine almost every object adhered quite aggressively to this identical-looking Dremel build tape once printing started, so maybe once the newness had worn off the adhesion would improve.

Dremel includes a plastic scraper to gently peel objects from the build tape, though a flexible thin steel-bladed scraper set from a pound store proved better for peeling off larger objects. In due course I expect a peelable film, a spray-on product or activator might become available for helping the first layers to bind and release better on unheated platforms like these. Some third-party aids are already starting to appear for the 'prosumer' user, and some users will doubtless experiment with adhesive tapes, low-tack spray-on adhesives or home-grown ideas to see what difference they make.

Apart from an initial false start, the results have been remarkable and several dozen objects were successfully completed in quick succession without a single hitch. If anything, reliability improved as time wore on, and I was soon printing with the Dremel 3D Idea Builder objects of various sizes and complexity, also creating my own objects online and then 3D-printing them effortlessly.

Dremel PLA is available in 10 colours including metallic and translucent. Looking ahead, Dremel warrants the 3D Idea Builder for use with its own PLA filament only, and they emphasise that only Dremel-branded PLA must be used to avoid the risk of damage. No doubt the matter of using third-party PLA will arise, just like the idea of using unbranded inkjet and toner cartridges once did. As there are so many variables at play, if the 3D printer is to work consistently then it's understandable why Dremel will not guarantee the performance with other brands or type of filament, especially if it results in a warranty claim for damage caused by, say, unbranded filament damaging the extruder head or by trying to print with ABS instead, which the 3D Idea Builder is not designed for. End users will decide whether to risk the cost of using third-party PLA, but personally I prefer the re-assurance of using a hassle-free product that guarantees consistent end results.

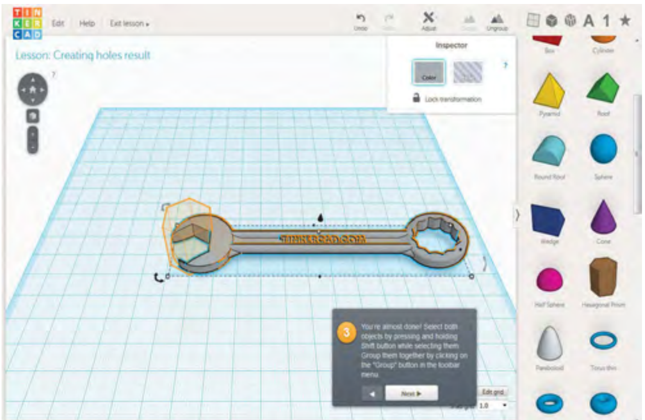
Dremel 3D software can import `.STL` and Dremel files and it controls the printer directly. Objects can be viewed or scaled on-screen

The printer had another 'well' inside to hold a second reel, plus fittings for extra fans on the rear, which hints at the potential for two-colour printing which more expensive machines can already offer. The Dremel 3D Idea Builder is in fact similar to the less well-known Flashforge Dreamer, which is a much more complex dual-filament machine with Wi-Fi control, and it is clear that the 3D Idea Builder is a collaborative effort and all the better for that. For domestic customers, the resources, support and backup of a well-known brand such as Dremel will be very reassuring.

Design it yourself

To download and try out more ideas, start at **https://dremel3d.co.uk/3d-printing-models** or you can customise some simple key tags or dog tags on the web via the 'Design Tools' link on Dremel's website, saving the resulting `.STL` file onto hard disk.

The future lies in building one's own designs though, and users will soon want to create their own objects. You can start with free web-based design systems like Tinkercad, which will give you a taste of designing 3D objects on-screen. Tinkercad has some simple online tutorials and basic shapes and alphanumeric characters can be combined to produce an `.STL` file for downloading into Dremel 3D. There are many online galleries where pre-designed files can also be exhibited, shared and downloaded, often free of charge, including **https://www.tinkercad.com/things/**. Import the `.STL` file into Dremel 3D, scale them, save as a Dremel format file, hit CTRL+P and away you go.



3D designs are produced using third-party software such as Tinkercad

I can envisage *EPE* readers building simple boxes for smaller projects, LED holders for fancy displays or illuminated novelties, loudspeaker or ventilation grilles, badges, instrument knobs, slot-in panels, plastic dividers or chassis mounts, airflow ventilation tubes, parts for buggies or robotics, levers and actuators, switch bezels, scales and much more – the scope for the electronics hobbyist is almost endless. Even small 3mm-thick PLA panels proved very tough indeed and the plastic can be painted with some success. Bear in mind the porous nature of printed PLA objects though, making them unsuitable for food use or chemical storage.

As mentioned, 3D design software is not included as CAD software can cost more than the printer. For more adventurous users, a free copy of Autodesk Meshmixer can be downloaded from **https://dremel3d.co.uk/3d-printer-software-apps**, which lets you shape, sculpt and warp a mesh in 3D and print directly to the Dremel. Also, a free

version of Autodesk 123D Design can be fetched, which will satisfy many ambitious users. Autodesk's free 123D Catch app (PC, Mac, iPad, Android, Windows Phone) can stitch digital photos (a minimum of three, but 20-40 is recommended) into 3D scans for printing but has not been tested by the author. Some software requires an online account and some have 'in-app' purchases.

The only limit is your imagination

Model makers of all sorts will find 3D printing a valuable addition to their hobby – robotics and animatronics, gadgets for marble runs or domino races, model war games and dioramas, architectural and educational models of every description, model railroads, doll's house furniture, fantasy objects, molecular models, simple jewellery, desktop organisers or almost anything else you want to make in plastic, you name it – the list is endless. If I had a 3D Idea Builder as a kid, my parents would not have seen me for months on end. Dremel has done a great job of bringing the prospect of 3D printing to beginners and everyday users alike, and the 3D Idea Builder will soon find a place in homes, schools and hobbyist workshops. 3D printing is fast becoming a whole new hobby in itself, and never has hitting CTRL + P been more satisfying and productive than it is now.

Specifications

Model No: Dremel 3D20

Type: PLA fused-deposition, single-filament extrusion

Filament: Dremel PLA 1.75mmø in 190 metre (0.5kg) reels, available in 10 colours. One reel of white PLA is included

Print volume: 230 × 150 × 140mm maximum. Unheated build platform, active cooling fan

Max (finest) resolution: 0.1mm/100µm/0.004-inch

Min (coarsest) resolution: 0.3mm/300µm/0.012-inch

Maximum temperature: 230°C (220°C default)

Screen: 3.5-inch IPS full colour touch screen

Software: Dremel 3D printer driver for Windows Vista+, Mac OSX 10.8+, Linux Ubuntu v14.xx 32 and 64bit. Note, 3D design software is not included, see text

Printer file formats: `.3dremel`, `.stl`, `.obj`, `.g3drem`

Ports: SD card, USB 2.0, mains IEC inlet

Memory: 4GB non-volatile internal plus 32GB (max) SD card

Accessories: SD card, wire unclogger, scraper, build tapes, USB and power cords, printed *Quick Start* and *User Guide*

Dimensions: 485 × 400 × 335mm, fully enclosed cabinet with removable lid, internal LED illumination and polycarbonate door

Weight: 8.8 kgs excl spool

More details from: **https://dremel3d.co.uk**

The Dremel 3D Idea Builder and Dremel PLA filament are available in the UK from Rapid Electronics, Stock code 25-0500. Price £698.99 + VAT. More details from **www.rapidonline.com**

NET WORK

by Alan Winstanley

IP security cameras

INTERNET SECURITY is not just about 'virtual' safety, you can also take steps to boost you and your home's physical security. This month's *Net Work* checks out a type of security device that is gaining popularity thanks to the increasing uptake of home networking and Wi-Fi. Technology has moved on since I last tested IP security cameras in the September 2012 *Net Work*, and so the time was ripe to search for a modern IP camera suitable for outdoor use.

An IP camera runs as a standalone device on a network, as opposed to needing a host computer. Some IP cameras can take HD-quality snapshots and decent video footage, and store it in the cloud or a local server connected to your router. They capture images in colour until ambient light falls to the point where infrared illuminators trigger and the image switches to monochrome instead. A so-called 'PTZ camera' can pan, tilt and zoom by remote control, and some can 'patrol', panning a preset area automatically. They may have a built-in microphone that relays sound back to the owner, while others have small loudspeakers that play (for example) a barking guard dog sound when movement is detected; or they could broadcast audio from the owner's microphone or mobile phone.

In theory, IP cameras can be accessed with a web browser or a mobile phone app from anywhere in the world that has a decent Internet connection, and many cameras will detect movement (a change in the pixel pattern) and send an SMS or email alert to the owner, taking a snapshot at the same time. Prices range from a few tens of pounds to many hundreds for high-end devices.

From a networking point of view, IP cameras obviously need an IP address to allow them to be reachable over the network. A home IP camera is typically given an 'internal' IP address by the router, which in turn connects to the Internet via the IP address supplied by the ISP. Depending on some router options, the camera's IP address might change from time to time (DHCP), or a fixed IP address can be set up in the router instead. These are still 'internal' IP addresses that cannot be accessed by the outside world. The principle of Network Address Translation (NAT) allows dedicated IP traffic to be steered through the router to the 'internal IP' camera and back out again.

If a router and IP camera are compatible with UPnP (Universal Plug n Play) then they should set themselves up on the network more or less automatically. Quite often though, getting to grips with router settings and various options can be a trial in itself.

IPv4: running short

One practical problem is that fixed IP addresses (as used by ISPs and broadband users) are getting thin on the ground. In the US, it was recently announced that America's pool of IPv4 IP addresses had finally dried up: these are the familiar 'dotted quad' IPs like 178.15.123.45 and there aren't enough of them to go round. The rapid increase of Internet-related devices meant that inevitably the limits of the IPv4 address space would be reached and they will start to be traded, so the adoption of IPv6 is getting closer. An IPv6 address uses *eight* groups of *four* hexadecimal characters, which allows enormous capacity for scalability and future growth. Some routers already have options for IPv6 to make them future-proof, and if you are in the market for a new router it's now worth looking out for this feature. More background details are at **http://ipv6.com**

To handle the need to access IP cameras online, third-party services such as **dyn.com** can be used to provide a dynamic IP handling function. The IP camera is then reached simply by logging into a bespoke URL. If the device's IP address changes, the DNS service updates itself accordingly. Some camera manufacturers offer their own DNS service to allow remote access, but this makes you entirely reliant on them to access your camera over the web.

Further issues arise if cameras need bespoke browser-based software and several cameras that I tried in the past had problems with legacy software that did not run well in modern web browsers. Having future-proof browser-compatibility is a factor that should be borne in mind, especially as web browsers are frequently updated. A mobile or tablet app is another solution, but that might need updating when Android or iOS are updated.

With so many technicalities to think about, choosing and using an IP security camera can be fraught with headaches, so anything that makes the process as painless as possible will be welcome. One product range that caught my eye is marketed by **UCam247** as 'Plug and View' IP cameras, which claims to be 'super simple' to install and set up. To monitor a driveway access I decided to try the Ucam247-HDO1080, which had a very impressive spec on paper: it is an HD 1080P weatherproof camera with Ethernet and Wi-Fi, with built-in storage and cloud access. With infrared illumination it claims a range of up to 15 metres at night, and it has multi-zone motion capture among other features.

The makers offer viewer software for PC and Mac, and free iPhone and Android apps for checking the cameras in real time. Images and video clips can be stored on an internal microSD card (not supplied) making the camera a digital video recorder in its own right, or externally on network-attached storage. More than anything, though, I wanted to see if the camera was as easy to set up as they claimed it would be!

The UCam247 NC328W-IR-1080 is a diecast bullet-shaped camera about 125mm long by 55mm diameter that is quite robust. It is sealed to IP67 and a metal visor helps shield the lens from the weather. A familiar Wi-Fi antenna reaches a good 150mm above, so allow some space for clearance under eaves or gutters, or maybe point it downwards instead. The image can be flipped with software if you decide to hang the camera upside down from the eaves, but

The UCam247 HDO-1080 is an easy-to-set-up wireless HD IP camera in a rugged weatherproof case

the visor cannot then be moved from 'underneath'. A ball-jointed diecast metal stand gives 100mm of stand-off clearance from the mounting surface, and is more robust than many I have seen.

One drawback is that cables are exposed, which in vulnerable low-level locations might be a weakness. A DC power lead and Ethernet lead extend 250mm from the rear. To route the leads indoors (eg, just inside the eaves or loft space) would need a ~30mm diameter hole for the Ethernet block, which might not be feasible. However as the Ethernet port is only needed *once* to set up the camera before handing over to Wi-Fi, it becomes redundant unless you need to set the camera up again in the future. It can be left dangling downwards outside, maybe sealed with self-amalgamating tape beloved of satellite TV installers. Happily, the makers recently launched a special waterproof junction box for terminating both the Ethernet and power leads. This is an excellent idea and after the camera has been initialised, just a single 10mm hole is needed for the 3m-long power lead to pass through to a mains supply located indoors.

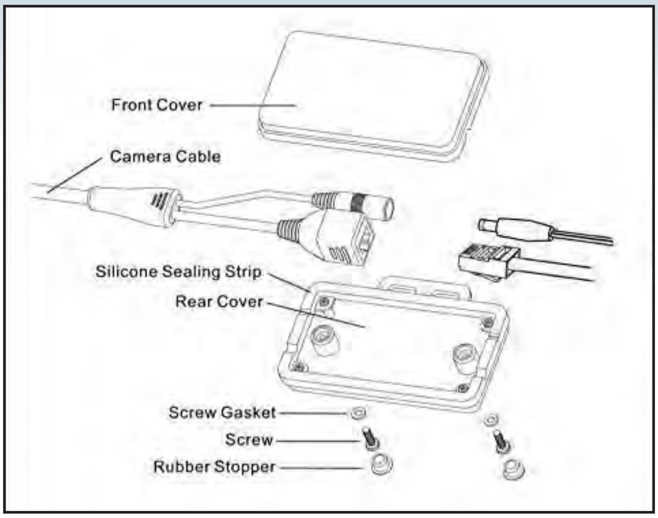
On the net

Next comes the camera setup itself, and this UCam247 IP camera uses an app to make the setup routine effortless. Labels on the camera show the UID and a handy QR code. The camera is hooked temporarily to the router via the Ethernet lead supplied, and the UCam247 Live app is installed on an Android or iPhone with Wi-Fi enabled. Simply run the app and choose 'Add camera': you can search or you can use a smartphone's QR code scanner to fetch the UID directly from the QR label. The IP camera's UID, username and password can then be entered and you can give the camera a user-friendly name. It's that easy! Using WPS (Wi-Fi Protected Setup) was another option that was not tested.

Viewing software for Windows and Mac can be downloaded, along with a Camera Finder utility. Initially, the settings are accessible via a web browser using the camera's IP address, and then the camera's wireless connection can be configured using the setup wizard. The initial setup was elegant and trouble-free, and in fact it could not have been simpler.

UCam's Camera Live software was the best way of viewing the video feed on a desktop PC. A mobile phone is fed with a lower-resolution image to preserve bandwidth. Using Camera Live View on a PC, the image could go full screen and be used as wallpaper, and you can take your own snapshots or record MP4 videos and save them in albums. Extra wireless cameras can also be added and viewed here. The camera's built-in microphone was extremely sensitive and can be trimmed or muted. Despite its HD credentials, you will not see HD motion video though – no cinematic experience here – and the frame rate depends on many factors, including your network performance.

Viewing directly in a web browser using the camera's IP address instead of Camera Live was problematic, as the default browser (IE11) constantly stalled when trying to run a plugin. It was found that Quicktime was missing and the QT plugin had to be enabled properly. This was always troublesome and Firefox was more dependable. Depending on the router settings, the camera's IP may change from time to time, so you have to re-discover it before logging in this way. It was simple to run the UCam app on an Android phone and connect to my camera using a guest Wi-Fi connection, so I could keep an eye on things from a distance. A paid-for service called Cammy (**www.cammy.com**) is suggested for cloud storage, but the author has not tested it.



UCam's new weatherproof junction box is a neat way of helping with drilling and cable routing

Motion potion

There are plenty of options to explore, but the software is largely self-explanatory. Next, I set it up to record events triggered by two motion detection zones (sensitivity can be adjusted), and movement causes snapshots to be recorded to (in my case) a dedicated folder on a Synology NAS. A sequence of five frames was taken when triggered by a passing car. I used the network path (`\\DISKSTATION\Ucam247`) with a human-recognisable name instead of sacrificing yet another drive letter. (Type 'net use' at a command prompt to see all your network drives and paths.) Hence, a shared network drive called Ucam247 now appears in Windows Explorer. Alternatively, the camera's microSD card could be used for online storage; it is installed on board by unscrewing the camera front.

I found that, as the IP address of the NAS changed periodically, recording of images would eventually fail, so I gave the NAS a fixed IP to cure this. This is handled in the router's settings: look for something like 'LAN and DHCP Server' settings and aim for 'Fixed Host' or similar. A fixed IP address must not conflict with any that the router's DHCP might choose from (up to x.x.x.199), so the NAS was given its own IP of 192.168.1.212. This must be repeated if the router is factory reset or its firmware is updated.

As this IP camera is ONVIF ready (the global open standard for setup of IP cameras with third-party devices, see **www.onvif.org**), more sophisticated security software such as Synology Surveillance Station can be used on the NAS for more professional multi-camera control. Compatibility was tested and confirmed, but it was deemed overkill for a simple domestic application like this. Extra ONVIF cameras can be added, but a Synology software licence is needed for each one. For prosumer users with bigger budgets, this would be a good way to go.

The remaining issues were practical ones of file management: living on a busy rural road it was unavoidable that passing cars or trucks produced multiple images, and the NAS gradually filled with no less than 42,000 snapshots. Don't even think of using Windows Explorer to delete them! Trying to erase old ones using the Synology's own file manager was a hateful task and impossibly slow. After much searching around, the solution was **Cyber-D's AutoDelete** (download from **http://cyber-d.blogspot.co.uk**), a 'donationware' Windows program that prunes folders by filename or date. Autodelete can delete files older than (say) 14 days and it can be run manually or in Task Scheduler. Deleting 20 or 30 thousand files was a lengthy job, but Autodelete was a blessing of a program that worked very well despite having one or two minor rough edges. As an oversight, Permissions had not been set properly to allow files in the Linux-based NAS to be deleted this way, but after allowing guest access, Autodelete worked as expected.

Cyber-D Autodelete can delete files by age to keep file numbers manageable

Cyber-D's Image Sequence Viewer will show CCTV images as a slideshow: useful for viewing IP camera images

The final question is how to *view* sequences of snapshots. Trying to view them over the LAN was impossibly slow due to the sheer volume of data, so I found it best to copy selections of interesting images to a new folder on a slave hard disk. Again, Cyber-D has a great answer in **Image Sequence Viewer**: simply point it to the folder of images and it displays them sequentially, and you can jog images or set the frame rate.

There are many IP cameras to choose from, but this UCam247 wireless HD camera scores highly on simplicity of setting up and usability. It was hassle-free to install and has been a pleasure to use. They have a number of indoor and outdoor cameras and to see a UCam Live camera in action, you can fetch the app for iPhone, iPad or Android and view the test camera live. More details are at **http://www.ucam247.com/wifi-ip-camera-easy-smartphone-viewing**

It costs around £160, and at the time of writing was available from **Eyespy24.co.uk** via Amazon.co.uk, and other outlets. See **ucam247.com** for details.

Next month, I'll show how you can convert an HDMI Smart TV to a fully-fledged Android computer and view UCam images live on TV.

You can email the author at **alan@epemag.demon.co.uk**

BY IAN BELL

Analogue switches – Part 2

LAST MONTH, we looked at the fundamentals of analogue switches – electronic switches built using MOSFET transistors that are used in both analogue and digital switching and signal routing applications (as distinct from power switching). The article was prompted by a discussion on the *EPE Chat Zone* forum, started by user ***cjay*** who needed a replacement for a BL1551 SPDT IC. The TS5A3159 from Texas Instruments (**www.ti.com**) was recommended by user ***gordon*** and successfully used by ***cjay*** to repair a circuit. We will start with a brief recap of the basic internal circuitry of analogue switch ICs before moving on to look in detail at their datasheet parameters and other considerations when designing with these devices. We will also look at a couple of common analogue switch applications.

The circuit of a basic analogue switch is shown in Fig.1. Two parallel complementary MOSFETs (N and P channel) are used because a single transistor would switch off for part of the input voltage range (on the A and B switch connections). We discussed this in detail last month. The parallel complementary transistors structure is called a transmission gate. An inverter is required to provide inverse control signals so that both transistors are either on or off together.

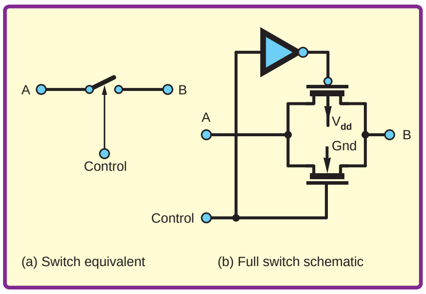


Fig.1. Single analogue switch built using complementary MOSFETs bilateral switch

The MOSFETs in the transmission gate have their substrates connected to the supplies, rather than shorted to the source as is usual for discrete devices; this is required to keep the substrate-to-source and to-drain bias correct while the switch operates symmetrically over the entire supply range. This makes it difficult to implement the circuit in Fig.1 using discrete components because these are rarely available as four-terminal devices. Fortunately, this does not usually matter because there are a large number of analogue switch ICs, which cover most applications.

Transmission gate

The circuit in Fig.2 shows how two transmission gates are used to create an SPDT (changeover) analogue switch. A

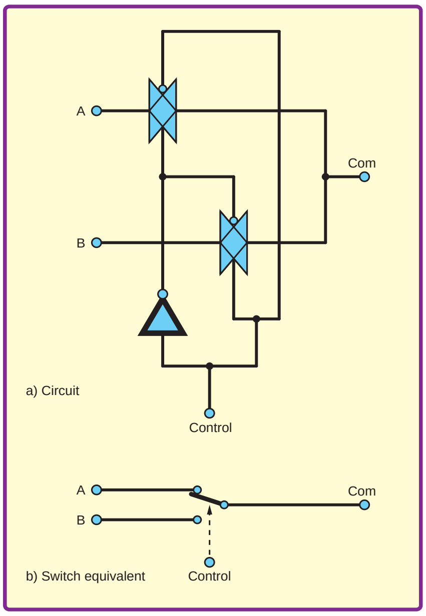


Fig.2. Schematic for a single-pole double-throw (SPDT) analogue switch

variety of basic switch configurations are available in analogue switch ICs. These follow traditional configurations such as SPST or DPDT. Do take care to distinguish, for example, a DPST (implying a single control) from a dual SPST (implying separate controls). Common configurations are shown in Fig.3, although the control inputs are not included for simplicity. As examples, full pinouts, showing the control signals, of the single SPDT TS5A3159, as used by ***cjay***, and a quad SPST TS3A4751 are illustrated in Fig.4. Both devices are from Texas Instruments.

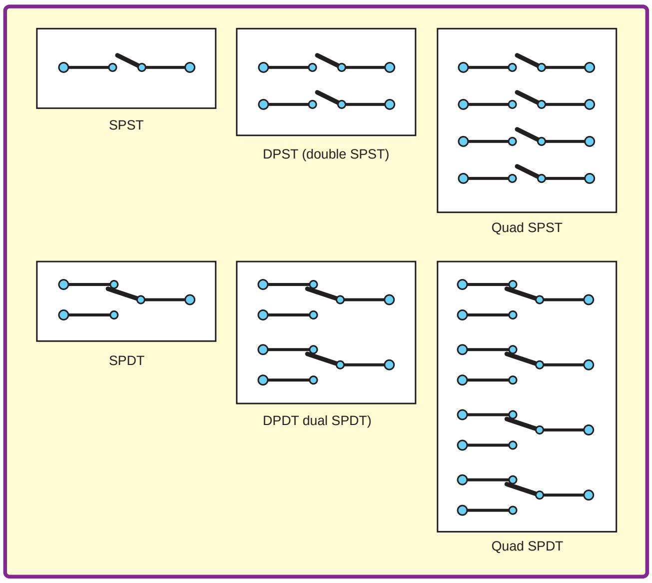


Fig.3. Typical analogue switch IC configurations for basic switch devices

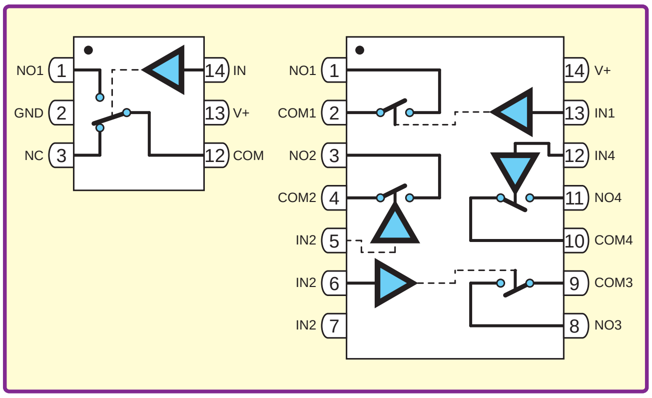


Fig.4. Example analogue switch pinouts. (a) TS5A3159 single SPDT switch and (b) TS3A4751 quad SPST. Both are from Texas Instruments

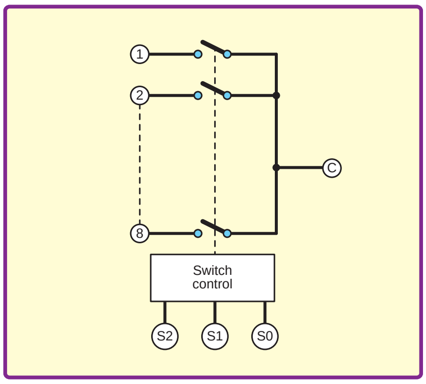


Fig.5. Example analogue multiplexer configuration, in this case an 8-way multiplexer. Binary select inputs, S, determine which switch is on and therefore which input is connected to the common, C

In addition to basic switches, a number of multiplexer configurations are available. These comprise multiple SPST switches, with a common input/output connection; driven by control logic such that only one switch is on at a time. They are equivalent to multi-way mechanical rotary switches. Typically, a binary digital input value selects the corresponding switch and determines which signal is routed through the multiplexer. There may also be an enable/disable input, which opens all the switches.

Multiplexers come in variety of 'ways', typically 2, 4 and 8 and 16. Some chips have multiple multiplexers (eg, dual 4-way). The naming is not universally consistent. A 4-way multiplexer could also be called a single-pole quadruple-throw (SP4T) switch. An example multiplexer configuration is shown in Fig.5. Like basic switches, multiplexers are usualy bidirectional, although some analogue multiplexer ICs have buffer amplifiers connected to common, making them unidirectional (output on common).

Applications and pitfalls

Analogue switches have a wide range of applications. Any situation where you migh need a switch in a circuit, with the convenience of electronic control is a possible candidate for their use. Two very common scenarios are signal source selection and setting circuit parameters, such as gain.

Fig.6 shows a typical source selection circuit. The analogue switch control ensures that only one switch is on at a time to select one of V_{IN1}, V_{IN2} or V_{IN3}, which is routed to V_{OUT}

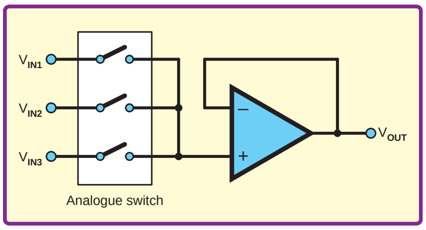


Fig.6. Analogue switch (multiplexer) used to select from one of several signal sources

via the buffer amplifier. One potential pitfull for designers of circuits like this is that changing the switch can result in very large and rapid changes of voltage on the input of the amplifier (that is, far more than would occur for the signal within any one channel). In such circumstances, the amplifier (or other circuit connected to the source selection switch) may behave poorly; for example, by taking a very long time to settle to the new input voltage. If voltage transient like this occurs in source selection circuits in audio systems then the result may be an auidible click or pop. In this example, a possible cause is difference in DC bias levels in the different channels.

The circuit shown in Fig.7 is an inverting op amp amplifier in which an analogue switch sets the gain. The switch determines which of two feedback resistors (R_{f1} or R_{f2}) are used to set the gain. In a high-precision application, the value (and variability) of switch 'on resistance' may be an issue, as it affects the total value of the feedback resistance. Gain is, for example, given by: $(R_{f1} + R_{ON})/R_1$ in the R_{f1} position. Using larger resistors will improve gain accuracy at the expense of increased noise.

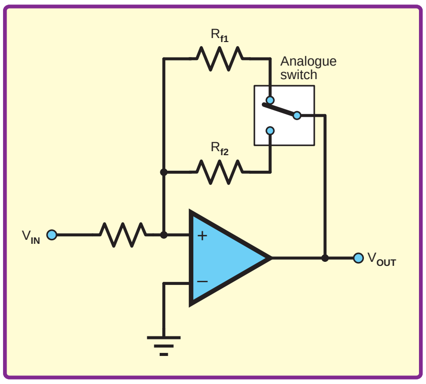


Fig.7. Analogue switch used to select amplifier gain

The problem can be reduced significantly by using a circuit that is less sensitivity to R_{ON}. In the circuit in Fig.7, significant current flows through the switch (about $V_{out}/(R_f + R_{ON})$) even with an ideal op amp, resulting in voltage drops that influence the circuit. By contrast, for the circuit in Fig.8, which uses a non-inverting configuration, the current in the switch with an ideal op amp will be zero. For real op amps with high input impedance the current in the switch will be very small. The gain in the circuit is set by the resistors (R_1 to R_3), which form a potential divider to determine the fraction of the output fed back. The switch selects between different fractions and hence gains. The load on the potential divider due to the op amp is very small, and adding the switch does not change this significantly. R_{ON} is not part of the gain formula for the circuit in Fig.8.

When designing a new circuit using analogue switches, or trying to find a

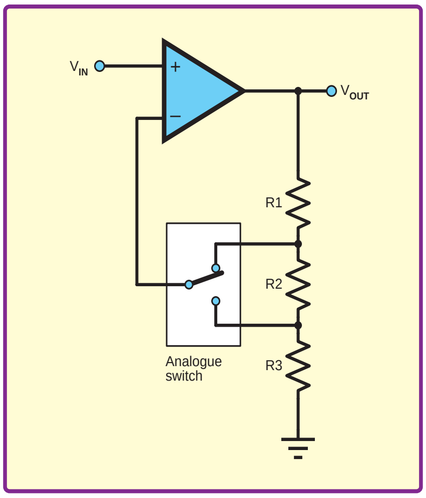


Fig.8. Alternative switch arrangement for gain setting

suitable equivalent for a repair, you will need to consult manufacturers' selection lists and datasheets. That is, assuming you do not have a friendly adviser to successfully suggest a device, as ***gordon*** did for ***cjay*** on the *EPE* forum. Therefore, we will now look at some of the key datasheet parameters and their potential impact on circuit performance.

On resistance (R_{ON})

We discussed on resistance last month. An ideal switch has zero resistance when on; mechanical manual switches tend to have very low on resistances, so are close to ideal, at least for low-to-moderate frequencies. 'Low resistance' analogue switches typically have resistances in the 1Ω to 10Ω range, but lower values are available. Other analogue switches have much higher resistance, particularly those from the 4000 series and similar logic families. In comparison, signal relays have typical contact resistances in the range 50mΩ to 100mΩ. The TS5A3159 has a headline on resistance of 1.1Ω and low on resistance is advertised as a feature of the device.

On resistance depends on control voltage, reducing as voltage increases. This means that on resistance will tend to decrease as supply voltage increases (assuming the switch control signals equals the supply voltage, or this is achieved via internal level converters). If multiple supply voltages are available in a system then it may be best to run a switch IC at a higher supply voltage (assuming compatibility) to reduce switch resistance. Fig.9 shows R_{ON} curves (R_{ON} against signal voltage on the common connection, COM – see Fig.4 for the pinout)

The temperature coefficient of R_{ON} for analogue switches is typically not very good – there may be quite significant changes in R_{ON} over the operating temperature range of the device. The value of R_{ON} increases with increased temperature.

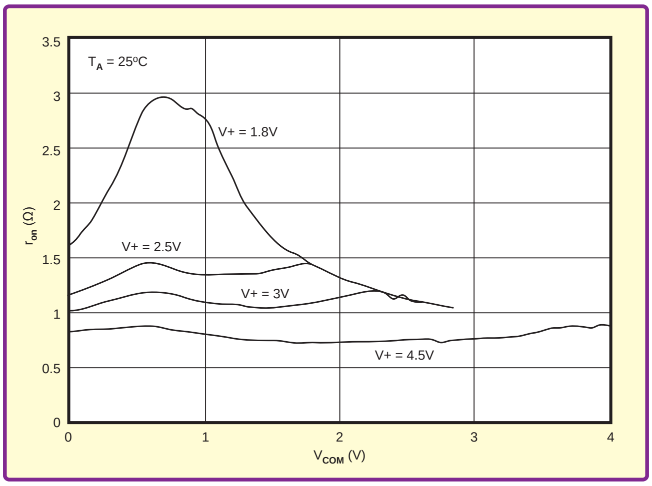


Fig.9. R_{ON} curves for the TS5A3159 at different supply voltages. Increased supply voltage reduces resistance. From Texas Instruments datasheet *(**www.ti.com**).*

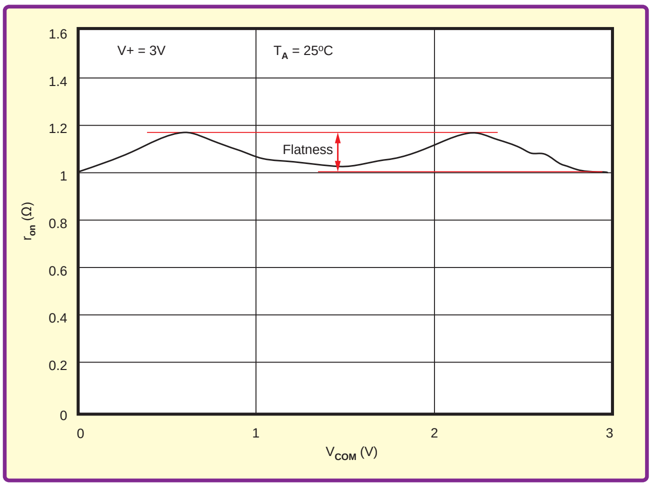


Fig.10. R_{ON} flatness for the TS5A3159 at 3V supply and 25°C ambient temperature. Based on data from Texas Instruments datasheet *(**www.ti.com**).*

Resistance flatness

As can be seen from Fig.9, R_{ON} is not constant as the signal voltage through the switch changes. Last month, we investigated this using an LTSpice simulation, which showed how the resistance of each individual transistor increases very dramatically as the signal voltage gets close to that transistor's switch-off point, but the parallel resistance is almost constant. The amount of resistance variation at a given supply voltage and temperature is called resistance flatness. The definition is illustrated in Fig.10 using data for the TS5A3159.

Resistance flatness is important because variation in switch resistance can cause distortion in circuits using the switches. For example, consider an amplifier in which the gain is selected by switching resistors using an analogue switch (as in Fig.7). As the signal voltage varies, the voltage on the switch and hence its resistance will vary. This will change the effective value of the gain-setting resistance (in series with the switch resistance) so that the gain will change with signal level, resulting in distortion. The effect will diminish if the gain setting resistance is increased relative to R_{ON}, but higher resistor values will result in more noise. The circuit in Fig.8 will avoid this problem.

Similarly, consider an analogue switch with a 1.0Ω to 1.2Ω resistance variation connected to a 50Ω load. The switch and load act as a potential divider attenuating the signal in the range of about 0.977 to 0.980. This is a 0.3% variation in attenuation factor with signal voltage, which will introduce distortion.

Total harmonic distortion (THD)

This is often expressed as a percentage and indicates the relative amount of unwanted output signal due to distortion compared to the wanted signal. As indicated by the above discussion, this is closely related to resistance flatness, but other factors may contribute to the total effect. The THD of the TS5A3159 is 0.01%.

Resistance variation/resistance matching (ΔR_{ON})

For ICs with multiple switches, the resistance variation or resistance matching parameter indicates the level of possible variation between the resistance of individual switches. This may be important, for example, in circuits processing multiple signal channels where the same processing parameters (eg, gain) must be applied to all channels.

Off isolation

An ideal switch is a perfect open circuit when it is off – no signal gets through. This is not the case with real analogue switches. The off isolation parameter indicates how much gets through the switch when it is off, usually this is measured in decibels (dB). The isolation usually gets worse as signal frequency increases, because higher frequencies are more readily capacitively coupled across the switch. The off isolation of the TS5A3159 is –65dB at 1MHz with a 50Ω load.

Off isolation is sometimes also called 'feedthrough', although the term 'feedthrough' can also be used to refer to the fact that the control signal can be coupled through to the signal being switched.

Crosstalk

It is common for analogue switch ICs to contain multiple switches. In such devices, the signal carried by one switch channel may be coupled to other channels. This is similar to isolation for a single switch, in that ideally no signal should get through from one switch to another, but in reality there is some capacitive coupling and the crosstalk will tend to increase with signal frequency. Crosstalk can also occur from the control signal to the signal being switched.

Charge injection

When a switch is closed, charge is present in the switch transistors – this is charge that happens to be flowing inside the device at that instant. The charge does not remain in the device when it is switched off, so it has to go somewhere in the external circuit – a process known as charge injection. Charge injection creates noise in the signal path. In the case of a switch connected to a sampling capacitor (eg, in a sample and hold circuit) the voltage level on the capacitor will shift due to the injected charge.

Leakage current

Leakage currents flow in the switch connection in both the on and off states, usually values for both on and off conditions are specified. As is common with semiconductor devices, in general, leakage currents are quite variable and highly temperature dependent.

Supply voltage

Just like other IC types, the supply voltage needs to be compatible with the rest of the system being designed. As already noted, the supply voltage affects on resistance. Many analogue switches can only handle signals within the supply voltage, so a device suitable for use on a split positive and negative supply would be required to handle negative signal voltages, including any AC signal biased at 0V. However, negative-swing-capable analogue switches that require a single positive supply are available. There are also analogue switches with charge pump circuits on chip, which produce internal supplies above the supply input and facilitate an extended signal-voltage-handling range.

The sequence in which multiple supplies are switched on and off may be important in systems employing analogue switches. Signal and control logic voltages should not be applied to analogue switches when they are not powered, except for devices that

are specifically capable of handling this. For this reason, the ideal switch-on sequence is the switch device first, then control logic, then the analogue circuitry handling the signals being switched. The switch-off protocol should reverse this.

Analogue voltage range and fault protection

The input voltage range of most analogue switches is basically equal to the supply voltage. As indicated by the above discussion on supply sequences, this only applies when the device is powered on. Analogue switches can be damaged by application of input voltages when powered down.

Some analogue switch ICs include additional circuitry to provide protection against over-voltages and voltages applied when the device is powered down. These devices are described as 'fault protected'; some even have outputs indicating that a fault condition is present. For example, the ADG5249F from Analog Devices (**www.analog.com**) is a dual 4-way multiplexer with fault protection and detection, which has outputs to indicate if its analogue inputs are experiencing overvoltage conditions.

Although many analogue switches cannot operate with inputs outside their supply range, devices are available which can handle negative voltages while operating from a single positive supply. Such ICs are described as being 'negative swing capable' or 'negative signal capable'. An example is the TS5A22364 dual SPDT switch from Texas Instruments, which can handle a –2.75V to +2.75V signal when operating on a 2.75V supply. Such devices are useful for preventing clicks and pops in audio source selection because they allow all signals to by biased around 0V, avoiding the problem with DC levels mentioned earlier.

Logic levels

The control signals of analogue switches are usually driven by digital outputs from devices such as microcontrollers. As with any interfacing between two logic chips, care must be taken to ensure that logic levels and voltage ranges are compatible. The analogue switch datasheet will specify the minimum and maximum voltages for both logic high and low at the control inputs. Logic outputs connected to the switch control inputs should produce logic levels within these ranges. If the logic outputs from the control source produce a voltage between the maximum low and minimum high levels the switch may still work, but it is likely that its supply current will increase, possibly by a dramatic amount.

Some analogue switches have logic levels that are relatively independent of their supply voltage and allow logic input voltages above the supply voltage. The TS5A3159 is 5V tolerant – so, for example, it can operate with up to 5.5V on its logic inputs when operating on a 1.8V supply. In general, the logic levels of modern analogue switch ICs will be compatible with one or more of the typical CMOS logic technologies with 1.8V, 2.5V 3.3V and 5V supplies. For example, the TS5A3159 logic levels only vary slightly with supply voltage, and are compatible with typical 2.5V, 3.3V and 5V CMOS logic levels over most, if not all, of its supply range.

Make/break sequence

For changeover (SPDT) switches and multiplexers, when the switch changes, one channel will start conducting and the previously selected one will stop conducting, It is highly unlikely these events will be perfectly synchronised (there are two transmissions gates involved, possibly with their own control/drive logic and independent and variable delays and switching times). Thus, either both channels will be conducting simultaneously (make before break) for a short while, or both will be open circuit for a short while (break before make).

In many designs it is essential that one of these conditions always occurs and the other never does – we will give a couple of examples in a moment. Therefore, analogue switches are often designed to guarantee break-before-make or make-before-break behaviour with the time of the 'overlap' or 'gap' being specified on the datasheet. For example, the TS5A3159 is a break-before-make switch, and the time when both switches are open (the break-before-make time t_{BBM}) is from 1 to 14.5ns on a 5V supply. This time gets longer at lower supply voltages.

A make-before-break switch should be used when switching between gain-setting feedback resistors in an op amp amplifier (Fig.7). If both switches are open, then the amplifier becomes open loop and its output voltage will likely hit one of the supply rails quickly, causing an output spike from which it will take time to recover once the second switch closes.

A break-before-make switch should be used when selecting between signal sources (Fig.6). If both switches are closed at the same time then the outputs providing the sources will be shorted together.

Turn on/off times

It takes a finite time from the point at which the control signal is changed to when the switch turns fully on or off. The switching times depend on factors such as supply voltage and temperature, but typical times for the TS5A3159 are 20ns and 15ns for on and off times respectively (5V supply). Switching is slower at lower supply voltages, for example increasing to 65ns and 40ns at 1.8V for the TS5A3159.

Switching times depend on the capacitance of the switch transistors. This capacitance is larger (producing slower switching) for physically larger transistors needed for low R_{ON}. Thus, low-R_{ON} switches are generally slower than those with higher resistance.

Frequency response

Analogue switches have a limit to the highest frequency they can pass. The switches have an inherent input/output capacitance, which, in combination with the on resistance, forms a low-pass filter. The maximum frequency varies significantly between switches on the market, with some specifically targeted at high frequency use, able to handle signals into the GHz range. The TS5A3159 has a bandwidth of about 100MHz. The frequency response of switches is typically shown on the datasheet as the loss in dB caused by inserting the on switch in a 50Ω matched line – that is the switch has a 50Ω on its output. The frequency response of the TS5A3159 is shown in Fig.11.

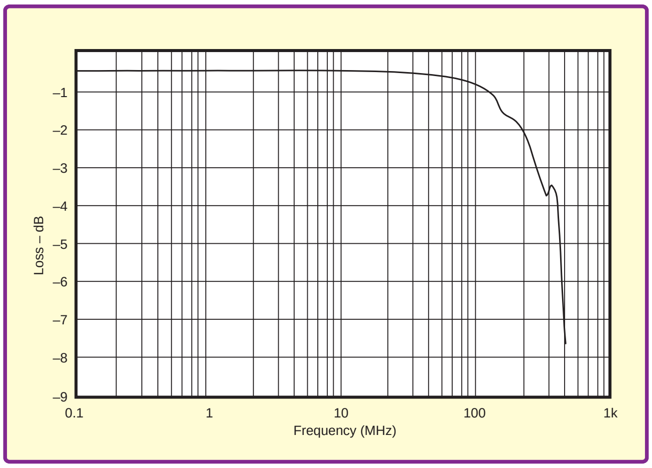


Fig.11. Frequency response of the TS5A3159 analogue switch. Based on data from Texas Instruments datasheet *(***www.ti.com***).*

By Robert Penfold

INTERFACE

PWM and legacy ports

THE PREVIOUS *Interface* article covered Raspberry Pi PWM (pulse-width modulation) using the built-in facilities that are now available for the GPIO port via the RPi.GPIO Python Library. This is fine as far as it goes, but in order to do something useful, some interface circuitry will usually be needed in order to process the 3.3V output signal of the GPIO port so that it can drive something like an LED or DC electric motor.

It is also possible to smooth the output pulses to produce an output voltage that is equal to the average voltage in the PWM signal. This is useful for loads that cannot handle the 'raw' pulsed signal from the GPIO port. It gives what is really a very simple digital-to-analogue converter (DAC). Due to the low frequency of the PWM signal, the rate of change of the smoothed output is very slow by normal electronic standards, but it could still be useful for applications where speed of operation is not an issue.

Power boost

In order to drive things like DC electric motors and lights, it is merely necessary to drive them via a high-power switching circuit, such as the one shown in Fig.1. TR1 is a Darlington power device that has very high current gain, and can drive up to about 2A or so, even though it is only receiving a drive current of a few milliamps from an output line GPIO port. A power Darlington transistor provides a relatively slow switching rate, which is obviously far from perfect in a PWM application. However, in this case, the switching frequency will be very low at around 50Hz to 100Hz, and the minimum pulse duration is likely to be about 50 to 100µs. A very fast switching rate is therefore not essential.

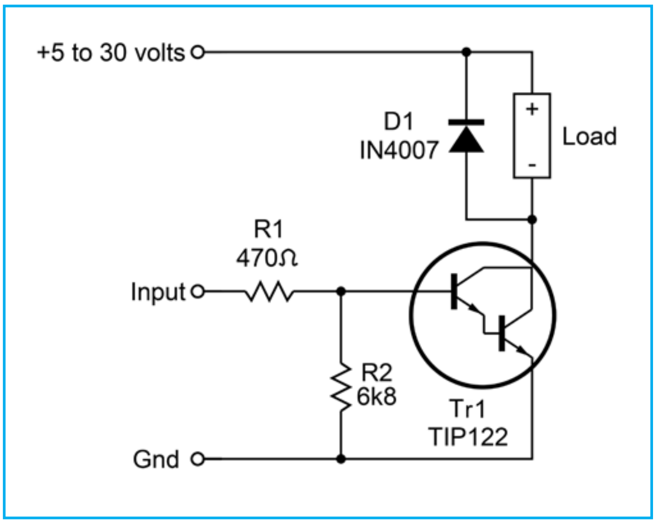


Fig.1. This simple driver circuit can handle loads of up to 2A. Tr1 should be fitted with a small heatsink

Protection diode D1 is only required if the circuit will be used to drive an inductive load, such as a DC electric motor. It suppresses high reverse voltages generated each time Tr1 switches off. Connection details for Tr1 are shown in Fig.2. There will be a small voltage drop through Tr1 when it is switched on, and to compensate for this the supply voltage needs to be about 1V higher than the maximum voltage

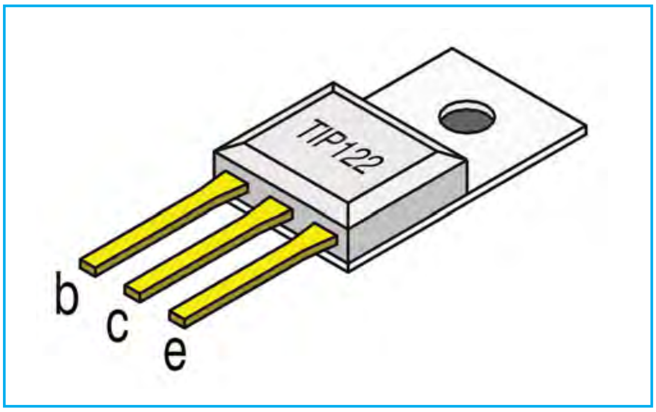


Fig.2. Connection details for the TIP122; the heat tab connects internally to the collector terminal

required by the load. The control accuracy of the circuit is dependent on a stable supply voltage, and it is therefore important to use a regulated supply. There is no built-in overload or short-circuit protection in the controller circuit, but a regulated supply would normally have current limiting or fold-back current limiting that will adequately protect the controller circuit and the load. It is advisable to include a fuse in the supply as well.

The maximum power dissipated by Tr1 will not be very high, even when maximum output power is being supplied, and due to the switching method of control it will be even less at lower output powers. However, a small heatsink will still be required to ensure that it does not overheat. It should be noted that its metal heat tab connects internally to the collector terminal, and care must be taken to ensure that no accidental connections are made to the collector via the heat tab.

Smoothie

Smoothing the PWM pulses to produce a steady voltage at the average output level is very simple in principle, and it just requires the addition of a low-pass filter. In practice, things are more complicated due to the low frequency of the PWM signal. Using a higher PWM frequency would ease the problem of smoothing the pulses, but would reduce the accuracy and resolution of the system. It is possible to smooth the signal using a single stage C-R low-pass filter, but the cut-off frequency would have to be set very low in order to give a low level of ripple on the output voltage. The settling time of the circuit would be measured in seconds rather than milliseconds!

An active filter with a higher ultimate attenuation rate gives better results. The circuit diagram of Fig.3 is for a fourth-order (24dB per octave) low-pass filter that has a cut-off frequency at about 10Hz. With the PWM signal set at 200Hz this would give something in the region of 86dB of attenuation to the fundamental frequency. This equates to an output ripple level that would never be more than a fraction of a millivolt. With a cut-off frequency of 10Hz, the circuit is still not particularly fast at responding to changes in the input signal, but it is sufficiently fast for some practical applications. It could be used as the basis of a computer-controlled power supply, or in computer-controlled audio applications where very sudden changes

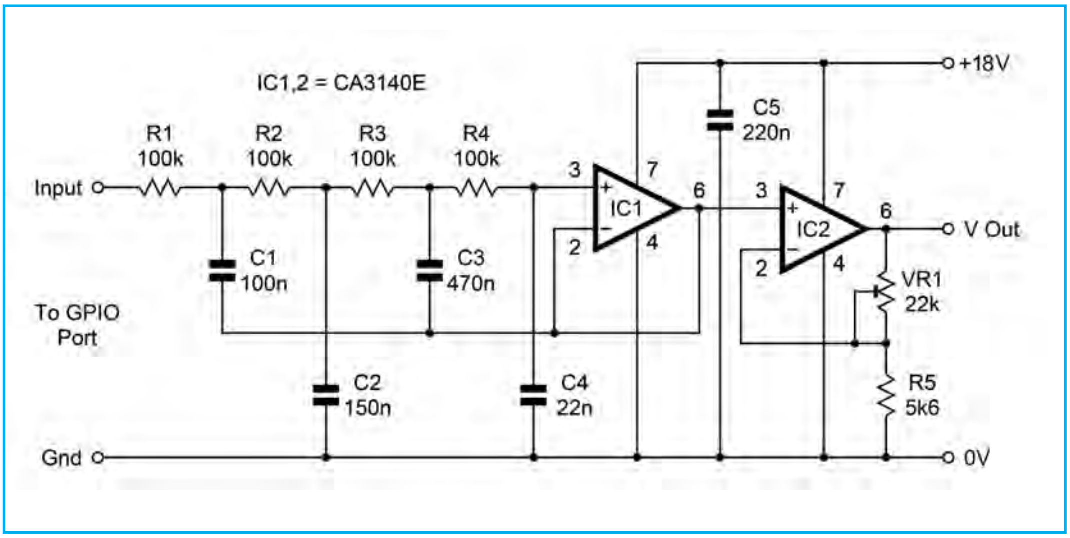


Fig.3. A fourth-order low-pass filter circuit to smooth the PWM signal. Ripple on the output should never be more than a fraction of a millivolt

are often undesirable and have to be avoided. PWM can be provided on several outputs at once, making it possible to have an inexpensive multichannel setup.

IC1 is the buffer amplifier in the active filter, and IC2 is used as a non-inverting amplifier at the output of the circuit. The output voltage range from IC1 is nominally 0 to 3.3V. The closed-loop voltage gain of IC2 can be varied from unity with VR1 at minimum resistance, to just over five times with VR1 at maximum resistance. This gives an output voltage range of 3.3 to 16.5V, but in practice the maximum output voltage might be limited slightly by the voltage drop through the output stage of IC2.

The CA3140E specified for IC1 and IC2 has a PMOS input stage, and it therefore requires the standard anti-static handling precautions. The operational amplifiers used for IC1 and IC2 must be a type that can function using a single supply. It would be possible to obtain greater accuracy using dual supplies and precision operational amplifiers. Using PWM can provide good resolution and accuracy, but for applications that require a very high degree of precision it would probably be better to opt for a conventional DAC.

Retro ports

We seem to be in an age of retro everything, and when buying a new PC I was surprised to find that many modern PCs seem to be fitted with what I suppose could be termed 'retro ports'. The correct term is actually 'legacy ports', and these are the interfaces that have been mostly replaced by USB ports on modern computers. The old Game/MIDI port seems to have sunk without trace, but PS/2, serial, and parallel printer ports have resurfaced on many modern PCs. When the legacy ports first disappeared from the rear panels of PCs they were actually still available via internal connectors on most motherboards. They could be implemented using a suitable lead and back-plate connector. Eventually, even this option disappeared.

For reasons that are far from clear, internal connectors for the legacy ports have returned, and some PCs even have one or more of them in the main cluster of ports at the rear. The port cluster in the example of Fig.4 is on a modern PC that has a fourth generation Intel i5 processor, but among the USB 2 and USB 3 ports there is a parallel printer type and a combined mouse/keyboard PS/2 port. The latter can be used with either a keyboard or a mouse. On boot-up, the BIOS program detects which of these is connected, and configures itself accordingly.

Fig.4. Legacy ports seem to be returning to modern PCs. This one has USB 2 and USB 3 ports, but also has a dual-purpose PS/2 port and a parallel printer (LPT) port

As I still have an expensive PS/2 keyboard, I found this facility very useful. It never worked reliably with a PS/2 to USB adapter, but works fine with the built-in port. An important point to remember with the PS/2 interface is that, unlike USB ports, it is *not* a so-called 'hot plug' type. In other words, a PS/2 device should not be plugged in once the computer is operating. It could be damaged, and it will not be detected by the operating system. It must already be connected when the computer goes through its initial checking sequence, and only then boots into the operating system.

Lacking drive

How much practical use the serial and parallel ports can be with a modern computer and software is questionable. On the face of it, there should be no problem if your PC has the right type of port for a peripheral gadget. However, with modern computers, external gadgets tend to be invisible to the operating system unless suitable driver software is installed. Drivers that enable old hardware to operate with a modern version of Windows are often unavailable. Old drivers can sometimes be made to work with more recent versions of Windows, but in most cases this does not work at all, or only gives limited functionality.

In the past, there were numerous home-built add-on devices that connected to the serial or parallel port of a PC, and these did not usually require any form of driver software. The application program communicated directly with the ports, and 'cut out the middle man'. As discussed in many *Interface* articles over the years, modern versions of Windows are very security conscious, and direct communication with ports is blocked. There are ways around this, but with modern versions of Windows it is not possible to directly read from and write to a port with the same sort of freedom that is available with a Raspberry Pi, Python, and the GPIO port.

This freedom was available with early versions of Windows, but when I tried installing Windows XP on two modern PCs the result was the same in each case. Initially, everything went fine, but about half way through the process it simply stopped. The chances of success with Windows 95, 98, or ME would presumably be even less. Strangely though, I found that going right back to MS/DOS and GW-BASIC was more successful. Although PC hardware has changed massively over the years, the original command set is still present in the modern Intel processors, and in

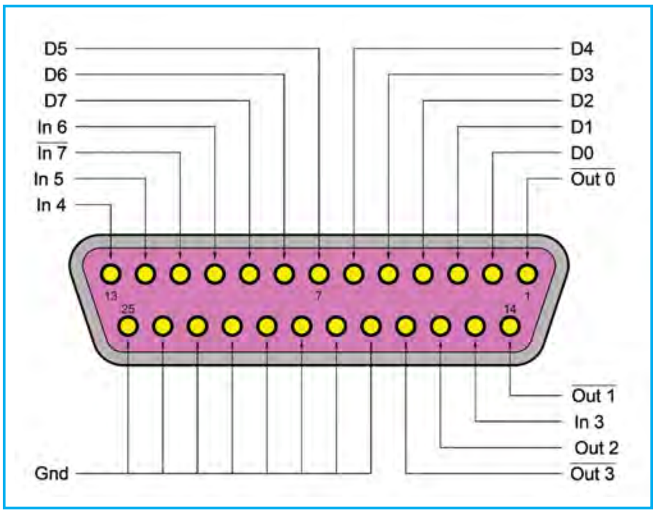


Fig.5. A parallel printer port has an 8-bit output that can be switched to operate as an input port (D0 to D7). Additionally, there are four input and four output lines, some of which have built-in inverters

Fig.6. A simple test in the direct mode of GWBASIC proved successful, with the 8-bit input of the parallel port being read correctly

my tests at any rate, modern video systems can revert to the old low-resolution display mode. A USB keyboard works as well, although it might be necessary to enable this feature via the BIOS Setup program.

Even if you still have MS-DOS and GWBASIC floppy disks, a modern PC does not have a floppy disk drive. It might be possible to use an external floppy drive on a USB port, but the more usual approach is to opt for a bootable USB memory stick. There are plenty of websites that provide details on making a bootable MS-DOS Flash drive, and adding GWBASIC or an equivalent program. In order to boot from a USB drive it might be necessary to make changes via the BIOS Setup program, but with many modern PCs there is an on-screen message at boot-up telling you to press a certain key in order to bring up a menu of boot options. The PC I used simply booted straight into MS-DOS without any intervention being required.

Inps and Outs

As an initial experiment I tried using the parallel port as an 8-bit input port. There is insufficient space here to go into detail about using the parallel port, but it has been discussed in many previous *Interface* articles, and there are numerous websites that give plenty of information about using it for general interfacing. Connection details for the parallel port are shown in Fig.5. It has an 8-bit output (D0 to D7) that can be switched to act as an input port. There are also four inputs and four outputs, which were used as handshake and status lines in its original role as a printer port. Some of these have built-in inverters, as indicated by a bar over the name in Fig.5.

In order to read the port it must be set to the input mode by writing a value of 32 to the control register, which is normally at hexadecimal address &H37A. The port is then read from the base address, which is usually &H378. You can check the base address of a serial or parallel port by looking at its details in the Windows Device Manager program. If the port is not listed there, it is probably switched off by default, and it will have to be activated using the BIOS Setup program. In the case of a parallel port, it should also be set to the bidirectional mode.

My simple test was successful, and an initial value of 255 was returned via a suitable Inp instruction. This is correct, because TTL inputs go to the high state when left unconnected. Pulling D3 low and trying again gave the correct reading of 247 (Fig.6). If a modern PC has a suitable port, it would seem that it should be possible to get it to work with old add-ons that use GWBASIC.

Using MS-DOS and GWBASIC also provides an easy way to experiment with and learn about computer interfacing. The direct mode of GWBASIC is very useful for simple interface experiments. I even managed to get Quick BASIC loaded onto the memory stick, and there was no difficulty in compiling and running programs that use the parallel port. One potential problem is that everything runs much faster on a modern PC, and program routines that once provided a delay of a second or two tend to produce no noticeable delay when using a modern 3GHz PC!

Max's Cool Beans

By Max The Magnificent

The Great ESCape

I am a man who wears many hats, so it's fortunate my noggin has such an accommodating shape. One of my roles is to act as the technical content director for the Embedded Systems Conference – 'ESC' for short (**http://bit.ly/1FKDHGC**).

Now, in this era of the Internet, a question I commonly hear is why should someone spend time and money physically attending a conference when so much information is available on the web? As far as I'm concerned, the answer is pretty obvious – the big difference is the fact that you get to meet other people.

I believe that networking with companies and one's peers is incredibly important. An event like ESC allows you to hobnob with your colleagues and to consort with representatives from companies like tool suppliers and equipment manufacturers. It can be very useful to make contact with others who are working in the same area so you can bounce ideas around. It's also advantageous to add people working in complementary fields – say wireless mesh networks – to your circle of acquaintances.

The problem is that many engineers' networking skills may most kindly be described as 'less than optimal.' There's an old joke that goes 'How can you tell if an engineer is an extrovert or an introvert?' The answer is that the extroverts will look at *your* shoes when they are talking to you (rather than focusing on their own footwear).

A cunning plan

What we need is something to break the ice. I have a cunning plan – a plan so cunning we could pin a tail on it and call it a weasel (as Black Adder might say). My idea is to create conference badges – one per attendee – boasting super-bright LEDs that flash out messages (patterns) effectively saying things like 'I R 1… R U 1 2?'

I've whipped up a quick Arduino-shield-prototype, as shown in Fig 1. The idea is that there will be six small DIP switches (the reason Fig.1. shows an 8-switch

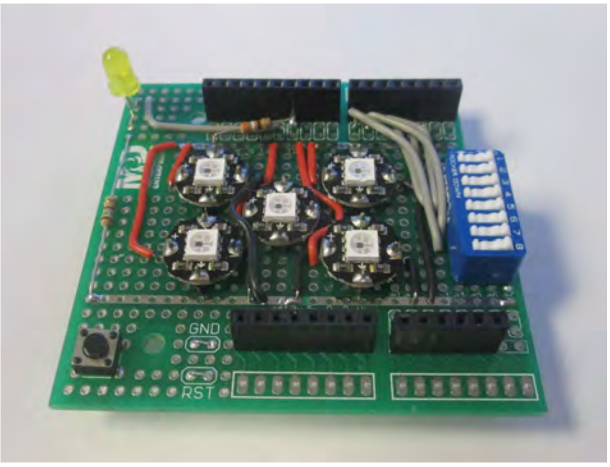


Fig.1. Prototype ESC badge

A	•–	M	––	Y	–•––
B	–•••	N	–•	Z	––••
C	–•–•	O	–––	1	•––––
D	–••	P	•––•	2	••–––
E	•	Q	––•–	3	•••––
F	••–•	R	•–•	4	••••–
G	––•	S	•••	5	•••••
H	••••	T	–	6	–••••
I	••	U	••–	7	––•••
J	•–––	V	•••–	8	–––••
K	–•–	W	•––	9	––––•
L	•–••	X	–••–	0	–––––

1) The length of a dot is one unit
2) A dash is three units
3) The space between parts of the same letter is one unit
4) The space between letters is three units
5) The space between words is seven units

Fig.2. The dots and dashes associated with International Morse Code

pack is that's what I happened to have lying around). These switches will correspond to major categories with which the attendees might associate themselves – I'm thinking 'analogue', 'digital', 'hardware', 'Software', 'IoT', and 'STEM.' Flicking a switch will cause the badge to flash a corresponding pattern in a certain colour. If you see someone else sporting that pattern-colour combo, you now have an opening to say 'Hi' and set the conversation rolling.

Of course, you may be associated with multiple groups – say 'Hardware + IoT + STEM' – in which case you would activate those switches and your badge would cycle around between the corresponding patterns and colors.

I'm assuming we're using tri-coloured LEDs. In this case (as discussed in my *EPE* August 2015 *Cool Beans* column), if we limit ourselves to simply turning each channel (sub-LED) on or off, then we end up with 2^3 = 8 different colour combinations: black (all off), red, green, blue, yellow (red and green), magenta (red and blue), cyan (green and blue), and white (red, green, and blue).

My idea is that if none of the switches are activated, then the badge will flash a default pattern corresponding to 'ESC' in white, which consumes the highest power. As soon as one or more switches are activated, we drop down to the six remaining lower-power colour combinations.

Dotty

But now we come to the 'Elephant in the room,' as it were. I've been waffling on about 'patterns' corresponding to the various groups, but what patterns should we use? Well, I thought it would add to the geek factor to flash these patterns in Morse code (see Fig.2.). Now, you

Fig.3. A pair of 'networking' Fritos cans communicating using Morse code

might say, 'But very few folks actually know Morse code these days.' Well, that's true enough, but it really doesn't matter – the people who don't know it will just see a flashing pattern, while the ones who are *au fait* with the code will appreciate the badges all the more. (Having said this, I had my prototype badge flashing 'Hello World' in Morse code when a colleague stuck his head into my office to ask me something or other and he immediately said 'Oh, Hello World!')

So, now we have to start thinking about the program we will use to display our Morse code messages. As part of this, we have to decide how we are going to store the dots and dashes used to represent each of the Morse code characters. You might take a moment to ponder how you might set about doing this yourself before perusing and pondering my solutions, as discussed below.

Strings and things

One 'cheap-and-cheerful' technique is to store the Morse code dot-dash symbols as strings of characters; for example, '.-' could represent 'A', '-…' could represent 'B', '-.-.' could represent 'C', and so forth. (You can access a test program based on this approach using this URL: **http://bit.ly/1KU7Z6K**).

Another approach would be to store each character in an 8-bit byte. Let's assume that we use 0 to represent a dot and 1 to represent a dash. In this case, as per Fig.2, 'A' would be represented by 01, 'B' would be represented by 1000, and so forth. One point to consider here is that the alpha-numeric Morse code characters require anywhere from one to five dot-dash symbols. If we simply 0-fill the rest of the byte, then how can we tell whether 00000001 represents 'A' (------01) or 'U' (-----001)?

One solution would be to left-fill the byte with 0s, and to use a 1 to indicate the boundary before the character. In this case, 00000101 would represent 'A', while 00001001 would represent 'U'. All we have to do is left-shift the byte until we reach the first 1, and then left-shift out the remaining dots and dashes (0s and 1s).

An alternative approach would be to use the three most-significant bits (MSBs) to define the number of dots and dashes, and the five least-significant bits (LSBs) to represent the dots and dashes themselves. For example, consider 'A' = 01000001 – in this case, the three MSBs (010) tell us that there are two symbols, while the corresponding two LSBs (01) represent the symbols themselves. By comparison, in the case of 'U' = 01100001, the three MSBs (011) inform us that there are three symbols, while the corresponding three LSBs (001) represent the symbols.

Tweaking the code

This is one of the schemes I played with, except I added a couple of 'tweaks.' First of all I reversed the order of the 0s and 1s representing the dot-dash symbols, so 'B', which would have been 10101000 (where 101 indicates four symbols and 1000 represents dash-dot-dot-dot), is now represented as 10100001. The reason I did this is that I can now easily right-shift the 0s and 1s representing the dots and dashes out of the byte.

My second modification was driven by the fact that punctuation characters in Morse code require six symbols (a comma is represented by '--..--' while a full stop is represented by '.-.-.-', for example). The way I get around this is to say that if the two MSBs are 11, then this indicates that we have six dot-dash symbols. (You can access a test program based on this approach using this URL: **http://bit.ly/1FL2Vo6**).

The wonderful thing about this sort of stuff is that there's always 'another way' to do it. If you know of a different technique, I'd love to hear about it (you can email me – see below). In the meantime, take a look at a video I created showing two Fritos (US corn chips) cans communicating using one of the Morse code schemes discussed above (**http://bit.ly/1VqvsGV**). (You can access the code for this at: **http://bit.ly/1WAd8bx**).

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

AUDIO OUT

By Jake Rothman

Speaking volumes – Part 2

Head scratching about pot scratching

Many of the problems related to volume-control pots are due to the simple fact that unlike most other electronic components, they include moving parts and use moving contacts. All pot technologies make a degree of 'whooshing' noise as they are turned, but wire-wound types are the worst in this regard. Cermet, a glaze made from ceramic and metal, is also considered bad, due to its hard rough surface. Most volume pots are 'carbon-based life forms' using sprayed carbon ink, a thin coating of the material similar to that used in carbon composition resistors. This thin track wears out after about 15,000 rotations (see Fig.18b). Some older more expensive pots are moulded carbon composition, which have a much thicker track and consequently longer life of around 25,000 to 100,000 rotations. A Plessey moulded track is shown in Fig.18c. Track linearity is poor, since the whole track assembly is hot moulded from powder, giving inconsistent dimensions. There are military (mil spec) moulded-track pots exemplified by the multi-sourced RV4 and Allen Bradley J-series. There is also the Allen-Bradley J 'extra-life' that lasts a million cycles. The best material for audio applications is conductive plastic or polymer, composed of epoxy bonded carbon, which is then printed and polished to an ultra-smooth hard coating, which can give lifetimes of over a million rotations. A polymer track is shown in Fig.19 from an Alps RK271, although for this device the spec gives a relatively short lifetime of 15,000 rotations. If you look carefully, the overlaid printed sections forming the log characteristic are visible.

Fig.18 a) (top) Standard sprayed carbon pot track; b) (middle) Worn carbon track; c) (bottom) Moulded carbon track from a Plessey E series pot. Note the thick track and the central collector ring for the wiper current. Used in old Neve consoles, I've seen these controls still working after 50 years

Track oxidisation

It's not just the track material that can wear out, the track wiper and the collector ring can also fail. I've spent many years replacing Omeg pots where the collector ring area oxidises, causing intermittent contact. When I complained, they said their biggest market was light dimmers, not the relatively refined market of audio. Apparently these devices need a small DC potential to maintain the contact. They supplied me with some gold-plated specials for Colorsound pedals which avoided this problem (Fig.20). Allen-Bradley ModPots are also prone to this problem, as shown in Fig.21. I was overhauling a Massenburg equaliser, and found that replacing the pots would cost over £20 per device – radical action was required. The solution was to use a Megger to apply 1000V to burn the high resistance oxide away. When the oxide is cleared, the voltage

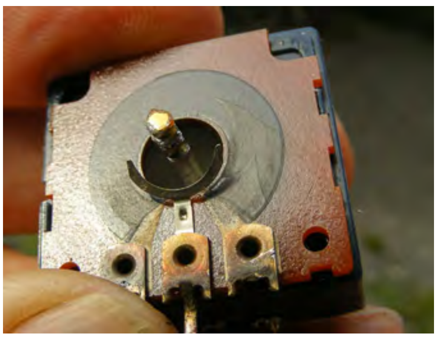


Fig.19. Track from Alps RK271 – note special printing pattern on track forming log characteristic

Fig.20. Gold-plated wiper assembly and collector ring reduce oxidation problems

Fig.21. Allen-Bradley ModPot with corroded collector contact/wiper assembly. The oxide was cleared with a high-voltage discharge.

Fig.22. Carbon brush wiper (from a Citec MH1) reduces rotational noise and is kinder to the track

drops then fall away rapidly without damaging the track.

An effective way of reducing rotational noise is to employ carbon brushes on the wiper and collector ring (Fig.22). This technique was employed in moulded track pots such as those by Plessey/Citec, Allen-Bradley and ITT/Eire. There is a catch though, due to the resistance of the brushes and track thickness. This results in a high end-stop resistance of up to 50Ω. This means the maximum attenuation, or 'offness' of the pot is limited. Not a problem for a normal Hi-Fi amp, but very bad for a mixer. The Bourns series pots solve both problems by having around 10 fingers on the wipers, and the Alps RK271 have 6, shown in Figs.23a and 23b. There's an excellent video (**http://tinyurl.com/pfryw5x**) on how Bourns pots are made on their site. A classic Bourns pot is shown in Fig.24, they have a characteristic blue colour, but watch out for fakes. Interestingly, Bourns cermet pots seem to be acceptable for audio applications, although their life is half of the conductive plastic versions due to faster wiper wear. Some pots only have one wiper, and guess what happens when it goes over a bit of dust? (loud crackle or even bang!). Electrical engineers hate moving contacts, witness the millions that have been spent eliminating the commutator brushes in electric motors – but they still persist, just take a look at your drill. 'Electronic' ways of controlling volume such as voltage-controlled amplifiers (VCAs) and switched FET arrays (eg, Dallas) avoid contact problems but suffer other serious problems, such as distortion, zipper noise (switches in steps, due to the use of a FET-switched resistor ladder) and control breakthrough (the control signal is superimposed on the audio signal).

Fig.23. Multi-fingered wipers reduce rotational noise. a) (top) Bourns 91 (yes there is a bug in the system!); b) Alps RK271

Switched volume controls

Some cheap radios may combine the volume control with the power switch (Fig.25). This is an audio *faux pas*. Most people like the volume setting to remain fixed and not have to be reset every time a device is turned on. I have come across many valve amplifiers where its mains wires are positioned just behind a high impedance volume control, with consequent hum. My Robert's RM30 solid-state radio makes a mains crackle at switch on/off that sounds so bad I sampled it as a sound effect. Some Hi-Fi amplifier designers go to great lengths to avoid signal contamination by positioning the volume pot at the back of the case right near the input sockets, with a long shaft to the knob on the front. Lazy designers just put the mains switch at the back.

Dual-gang pots

Most log dual-gang pots have a spec of 3dB difference for channel matching at an attenuation of –20dB, which is appalling and does not cover the all-important initial tracking (low volume section, where human ears are most sensitive to level differences). Even normal listeners can hear differences of 1dB between channels. Many audio manufacturers have to individually test pots and use the best ones for volume controls and the others for less critical positions. A rejection rate of over half is common. I remember seeing a special test jig at Studiomaster involving logarithmic amplifiers just to check log track matching. I've built a couple of simpler systems myself – one is a plug system that lets me listen to or check the channel tracking errors of a pot on a dual-beam 'scope. Another is to feed both wiper outputs into a high-impedance differential amp, feeding a centre-zero meter to measure the tracking deviation. I'll show these soon.

Fig.24. A pot classic – the Bourns 91 and its derivatives, characterised by their blue cases. These units are free from most pot vices, but are rather expensive

Fig.25. Combined volume control and power switch – please don't do it!

Stepped volume control

An audio system is almost a musical instrument, where continuous smooth control is expected. There is a lunatic fringe branch of the Hi-Fi fraternity who like the precision dB steps and channel matching offered by a switched attenuator. An expensive gold-plated Elma-switch-based attenuator is shown in Fig.26. This system is difficult to use – there just never seems to be enough steps lower down. Those using rotary switches seem to have a maximum of 29 steps, which I find too coarse. Finer stepped designs, such as Chandler's studio

Fig.26. Switched attenuator – very accurate, but expensive and unpleasant to use

Fig.27. Tapped potentiometer track – as used in the Colorsound Swell to give full-range operation with the limited travel mechanism employing just 50% of the available track.

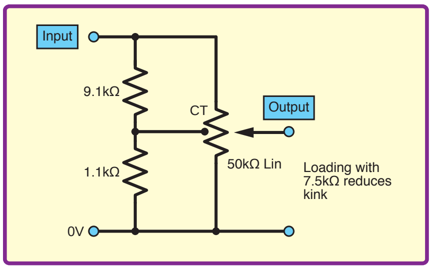


Fig.28. Tapped linear pot gives an approximate log law with a kink. Loading smoothes the kink out

control units use multiple relays, but their faint mechanical clicking annoys me. Some Japanese amplifiers have a little notched wheel on the volume pot to give a stepped feel. I just snap off such contrivances!

Tapped pots

An extension of the loading trick is a tapped potentiometer (Fig.27). A circuit by Baxandall in Fig.28 can give very smooth results, but tapped pots are rare. A motorised tapped volume control from Alps is shown in Fig.29a. These are used to provide a loudness control function, as shown in Fig.29b. Personally, I prefer to use tone controls and dial up the exact amount of boost I need if listening at low volumes. Tapped pots are usually special parts that cause replacement problems.

Cascaded pot systems

One method of getting a smooth log action is to put two linear pots in series. Out of curiosity, I developed the circuit in Fig.30, which is very smooth – but what's the point? The failure rate has been doubled because it uses twice as many moving contacts, and it needs a quad-gang pot for stereo. Occasionally, in very old audio systems using the 600Ω standard, constant impedance controls are found with three sections.

Faders

The renowned Penny and Giles studio faders (Fig.31) employ multiple taps to engineer the perfect subjective law. Fig.32 shows the curve, which is simulated by straight portions joined together. The complex track pattern is shown in Fig.33. Some faders have an isolated earth segment at the bottom of the track to ensure they can be fully turned off. A channel strip from an Audio Developments broadcast mixer (Fig.34) shows typical fader marking in dB, with 0dB indicating unity gain, +10dB gain at the top. Attenuation goes down to –60dB and right at the bottom it is 'minus infinity' or off. (If you try and calculate the log of zero on your calculator it will say 'error').

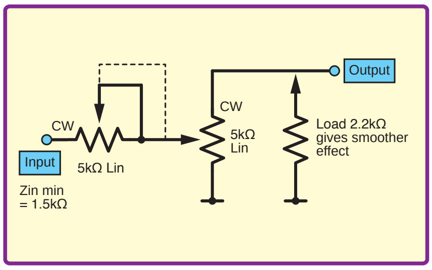


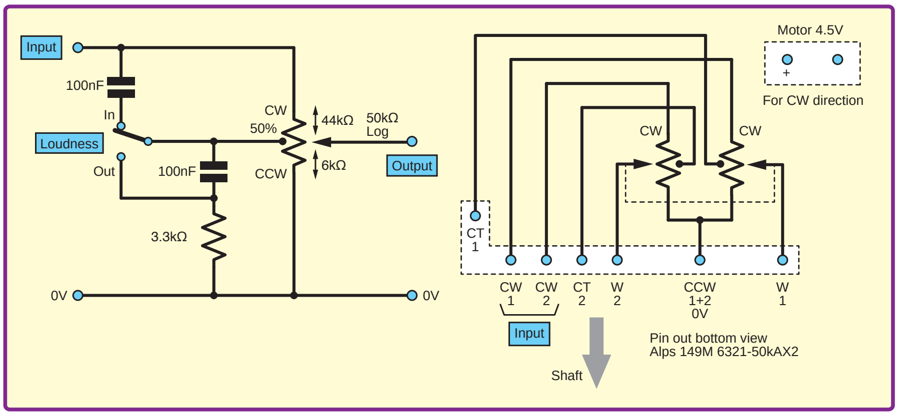
Fig.30. Two linear pots in series give a nice smooth log law – but with double the contact problems

Fig.31. Penny and Giles conductive plastic fader. These £50.00-plus units are the best I have come across, but what do you expect from the company that makes aviation 'black-boxes' (which are actually orange!)

Knobs

Tactile feel is an essential part of audio design; the volume knob is the part that the user accesses most frequently. A big knob is needed with a stiff pot. If the knob feels too loose, a felt washer from the sowing machine shop often works and also prevents ingress of foreign matter.

Some pots have excessive play, which can be disconcerting. It can be especially bad with pots having plastic



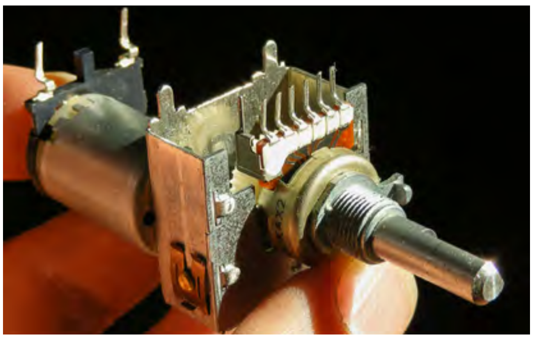


Fig.29 a) bottom left) Alps RKX204 149M motorised tapped pot with loudness function. This type of control is popular on Japanese Hi-Fi amplifiers; b) (top) Wiring Alps tapped pot. With the loudness switched in there is a 7dB dip at 1.8kHz with the pot at –20dB. This gradually disappears as the volume is turned up. The track is a standard log A taper with a 50% tap; c) (bottom right) Dual concentric polymer track construction from Alps 149M. The two different value halves of each track can be seen.

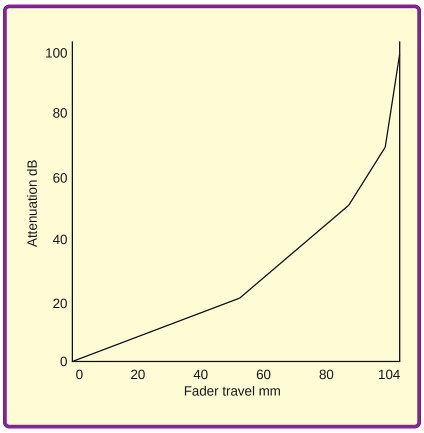


Fig.32. Penny and Giles piece-wise-linear log law provides the optimum subjective effect combined with ease of control

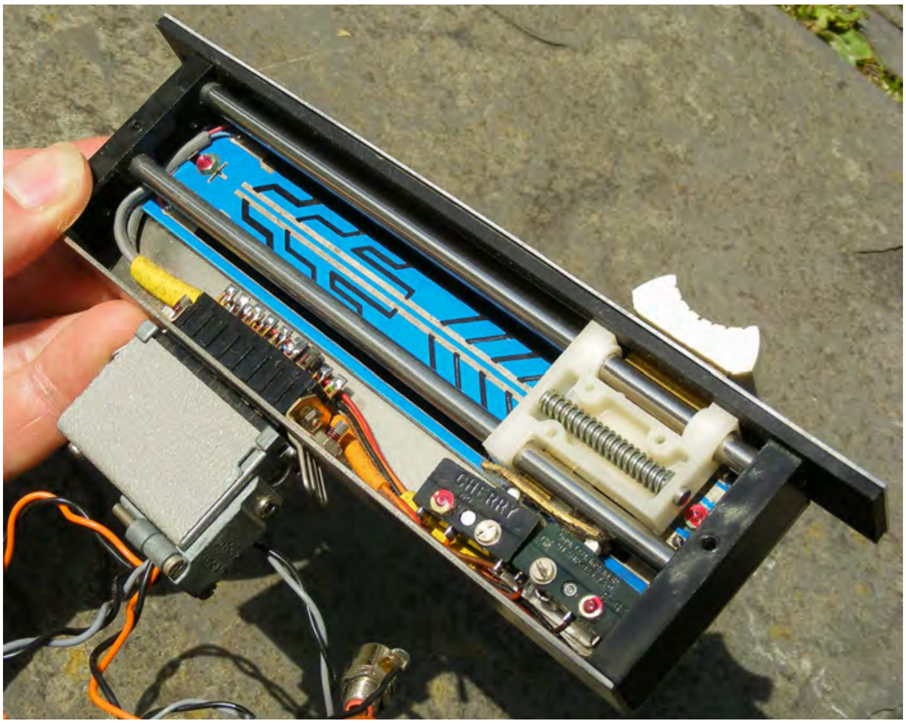


Fig.33. Penny and Giles fader track showing multiple tapping points

shafts, indeed sometimes they snap off. I once put 15 different manufacturers' pots in a box and passed it around for people to twiddle and say which one they thought had the best mechanical characteristic. Surprisingly, the cheap Alps RK16 and Alpha pots were the favourites, with their smooth greased feel. Some of the most expensive units felt loose and wobbly. In the audio components world you don't always get what you pay for.

Going to pot

Another mechanical problem with pots is the constant twisting and vibration they impart to the PCB. This can cause the pot track or soldered joints/PCB pads to break (Fig.35). One way round this is to buy metal support brackets for pots. For single-gang Alpha pots, which are especially prone to these problems, I put dual-gang pots in and parallel the pins (see Fig.36). It costs less than adding a bracket and reduces the noise by 3dB. Expensive equipment, such as the early SSL and Midas mixing consoles, have their pots connected to the PCB with stranded flexible wire. It is possible to by little PCBs, illustrated in Fig.37, from xulingmrs (a Hong Kong eBay shop) to enable wires to be easily connected to PCB-mount pots, such as the ALPs RK series.

The problems with stereo mis-tracking on volume controls are so common, I once heard a Hi-Fi salesman say that's what a balance control was for! Some designers just gave up and used two mono controls – an ergonomic disaster. Others put two knobs on one shaft in a dual concentric arrangement (Fig.38) that could hopefully be turned together and adjusted as necessary relative to each other. Omission of the balance control, making the signal path shorter, was the marketing angle. If we had followed stereo inventor Blumlein's original plan of middle and side stereo, instead of left and right, this constant problem of channel balance could have been avoided. We will develop this idea later.

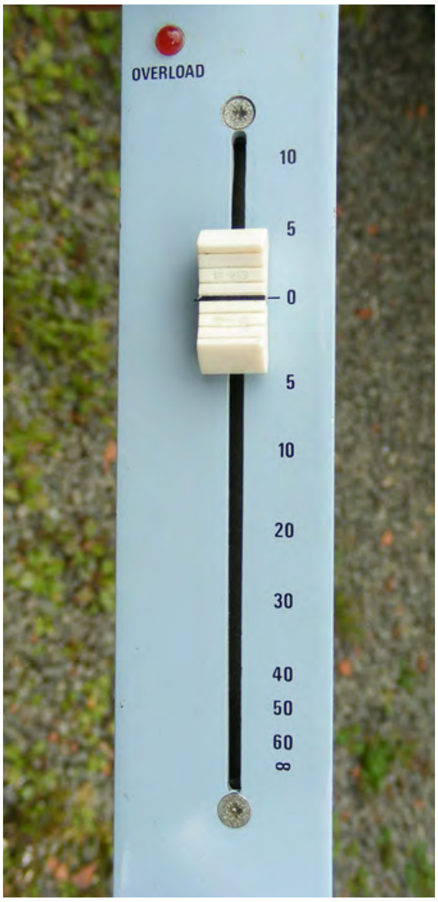


Fig.34. Channel strip from Audio Developments broadcast mixer – note fader marking. In dB terms, infinity means off

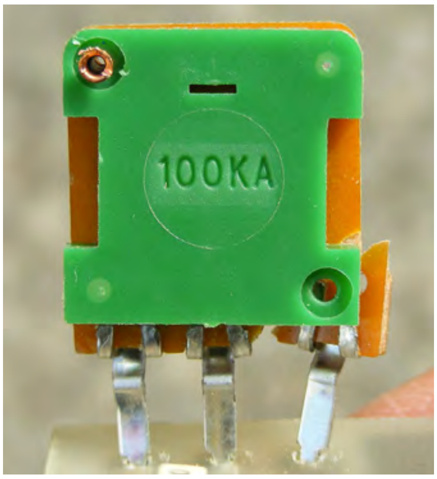


Fig.35. Mechanical stress between pot and PCB can result in cracked joints / pot tracks

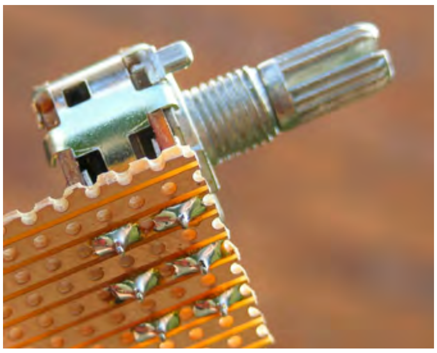


Fig.36. Paralleling cheap dual pots results in much stronger PCB mounting and reduces rotational noise

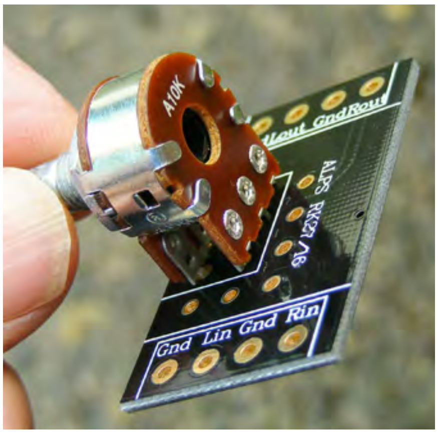


Fig.37. Special mounting boards for PCB-mount pots enables wires to be connected, avoiding in-use strain issues

Fig.38. Dual-concentric pot – has one shaft inside the other

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

How to pick a PIC

LAST MONTH, we had a look at mikroElectronika's mikromedia for PIC32, with all its bells and whistles. This month, I'd like to go back to the fundamentals of starting any new project. How do we go about choosing the right PIC for our design? This is a daunting task; there are more than a 1000 different microcontrollers from Microchip alone to choose from, and all of them have their strengths and weaknesses. We could of course just select three to four PICs we could use on each and every project. This is a hard-and-fast approach, which works for some, but not for others.

Microcontroller *vs* microprocessor

First off, what is a microcontroller? The words microcontroller and microprocessor get interchanged a lot, but there are a few subtle differences between the two categories. The microprocessor contains only the processing unit, also known as the CPU. It generally does not contain RAM, ROM or I/O pins. It uses its pins as a bus to connect to memory or other peripheral devices. These are commonly used in personal computers (like Intel's i3, i5, i7 and AMD's FX range of microprocessors), as well as mobile phones and general-purpose applications. Microcontrollers, on the other hand, contain their own microprocessor as well as their own memory and many other peripherals, all packaged in a reduced-size and reduced-cost IC. This makes them ideal for small, embedded systems, where we might want to hook up a load of LEDs to general-purpose pins and blink them individually – not easy with a microprocessor.

Where to start?

We have a number of methods and tools that will help us select the right PIC for our application. Most of the time we'll just go with whatever PIC we have lying around. However, if we want something more specific, such as adding a TFT LED touch screen interface, where we need a parallel master port, as well as four ADC channels, then we'll need to have a better method of narrowing down the selection. Microchip have their own tool, called Microchip Advanced Part Selector – MAPS for short (see: **www.microchip.com/maps/microcontroller.aspx**). MAPS allows us to select between various family of microcontrollers – for example, 8-, 16- or 32-bit devices. It also allows us to narrow down our selection based on specific features we're looking for, and it provides datasheets and budgetary pricing.

Let's have a brief look at the core features we're interested in and what will drive our decision:

1) Bit size and memory size
2) I/O and pin count
3) Speed or frequency
4) Debugging capabilities
5) Communication, analogue and digital peripherals
6) Timers

8, 16 or 32 – does bit count really matter?

What exactly do '8-bit', '16-bit' or '32-bit' refer to, and does it really matter? Which one is better? This is a hotly debated topic and strong arguments can be made for each. It really is down to what we want to do with our PIC. When we say 8-, 16- or 32-bit, we're referring to the data bus and address bus size of the microcontroller. In an 8-bit controller, we can use integers ranging from 0 to 255 (2^8) when unsigned and –128 to 127 when signed. In 16-bit controllers we can use 0 to 65,536 (2^{16}) unsigned and –32,768 to 32,767 signed and in 32-bit we can use 0 to 4,294,967,295 (2^{32}) unsigned and –2,147,483,648 to 2,147,483,647 signed. This also affects the address bus as well. In 16-bit controllers, we can access 65,536 bytes of memory and up to 4GB in 32-bit controllers (although the largest flash memory is only 512KB). However, in the 8-bit PIC18 family, the address bus can in fact access 16-bits (plus access bit = 17), which allows up to 131,072 ($2^{16+1} = 2^{17}$) bytes of memory.

What this really means is that when we move from using an 8-bit controller to a 16-bit or 32-bit one, we will have fewer restraints and more resources, like memory and the width of registers for performing arithmetic operations in our software. When using an 8-bit controller, we have to be more aware of these restraints. This becomes more apparent when writing in assembly language because adding a 32-bit number with an 8-bit device can be a real chore due to the necessity of using *atomic* operations. (Note: atomic operations are used on critical sections of code when performing any operation that uses integers *larger* than the bit size of the controller. It is necessary to make a number of instructions appear as one instruction, which must then be wrapped in a disable/enable interrupt pair. As a result, integer sizes using larger than 8 bits in an 8-bit microcontroller will result in inefficient code. In C, these problems are more transparent).

I really should clarify that there are actually various memory types inside every PIC. There's *program memory*, where our program is written to and loaded from. There's our *data memory*, which is where we load our program to during runtime and which stores all other volatile data. Finally, some PICs also have internal EEPROM memory to store non-volatile data during power off.

It could be assumed that 8-bit microcontrollers are the oldest, 16-bit are newer and the 32-bit controllers are the newest, and hence the older the controllers, the cheaper they are. For the most part, this is safe to assume, but it is not always the case, so always check prices.

Back to the big question, 8-, 16- or 32-bit? 32-bit architectures offer higher speeds, can process instructions faster, and can minimise time in active mode to return to sleep mode to reduce power. Their pipelined architectures (known as MIPS in PIC32s), enable 32-bit PICs to fetch, store and execute multiple instructions simultaneously. Obviously 32-bit microcontrollers *look* like the better option. However, Microchip have put significant on-going investment into their 8-bit product lines, starting with their baseline architectures (PIC10, PIC12 and PIC16) increasing their features to their mid-range and enhanced mid-range architectures to make them more cost effective with more performance and memory. Microchip's beefiest 8-bit microcontroller is the PIC18, which is designed for high performance and is optimised for C programming with advanced peripherals. The main advantage here is the compatibility with legacy code. Microchip have worked hard to try and make sure the same code used on an 8-bit microcontroller can be used on 16- and 32-bit controllers. The `Timer0` function (a register whose value increases

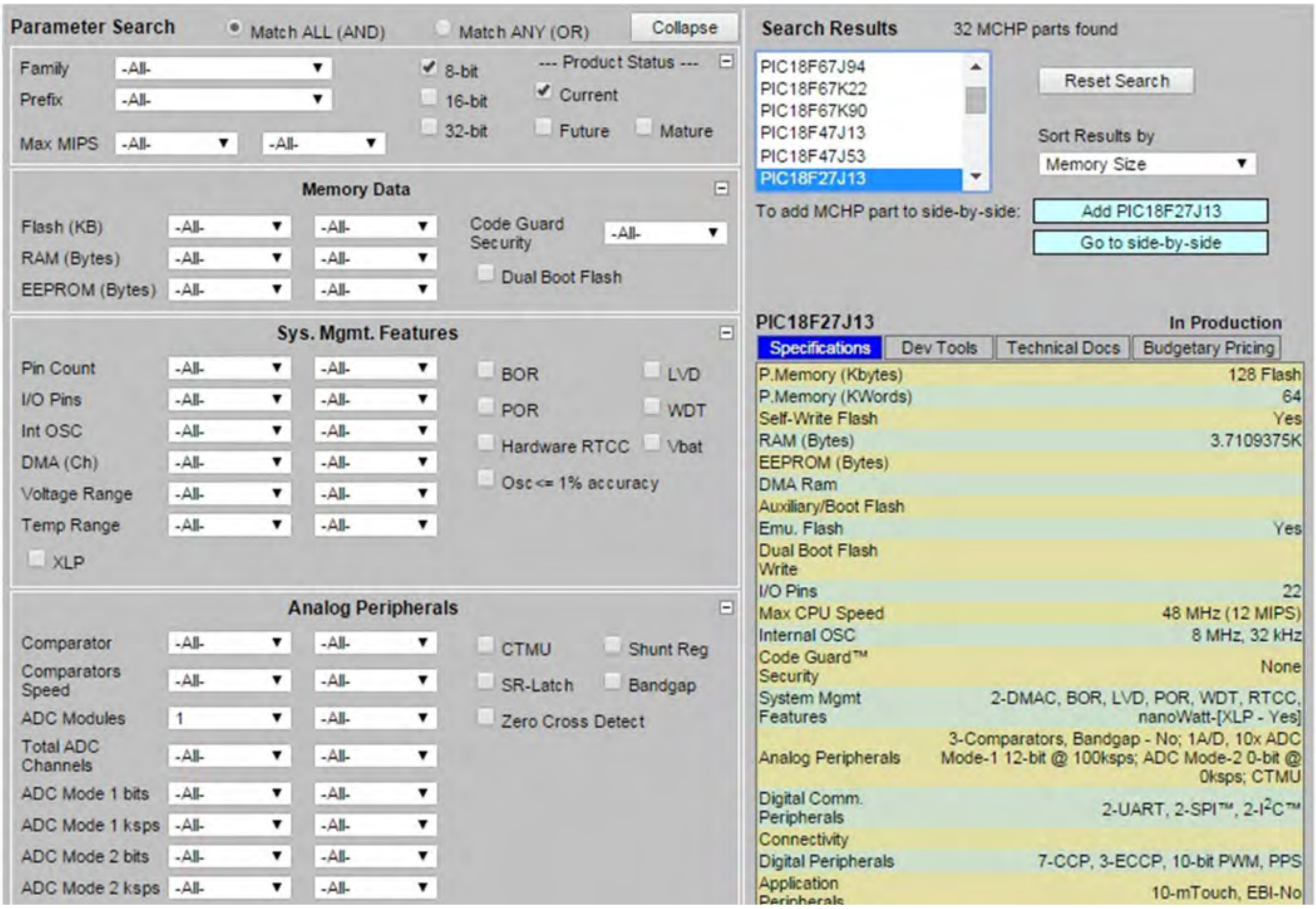


Fig.1. The Microchip Advanced Part Selector (MAPS) interface for selecting PICs

every CPU clock cycle to accurately time events) is a prime example of a function than can be used in many of the PIC product families, but it isn't always the case.

The 8-bit choice

Simplifying our selection, the general hard-and-fast choice for us is an 8-bit microcontroller. Usually, they are available in through-hole package sizes for breadboarding or rapid prototyping. They can be coded in either assembler or C, and they will cover most projects we look at. This also means using the same 8-bit compiler – plus, any previous software we've written can easily be ported over. If we want more processing ability, need to perform larger math equations or use more memory, then we could look at the 16- and 32-bit offerings. Surprisingly, I found programming in 32-bit microcontrollers a lot easier as I wasn't as constrained in terms of program and data memory and we don't need to be as careful when writing our code to make it all fit in the limited memory space. However, a separate compiler is needed for each bit size.

I almost forgot to mention dsPICs. These are part of the 16-bit product family and are geared specifically towards digital signal processing (DSP). These are typically used for digital sampling of continuous analogue signals in order to measure, filter, process or compress them for various purposes. An example is taking a sinusoidal voltage input, transforming it to the frequency domain using a fast Fourier transform (FFT) and applying filters to remove un-wanted frequencies. This could be very useful in filtering noise from a sound source and converting it to an audio file.

I/O and pin count

This really determines the size of the processor. Ideally, we want this as small and accessible as possible. But, it's always a good idea to have a few extra pins for backup – we never know what added functionality we may have forgotten. But remember, we have the option of connecting a port expander instead of using a PIC with more pins.

Speed or frequency

PICs can reach up to 120MHz with an external clock and up to 32MHz with the internal RC oscillator. If we need to perform operations at this frequency, then go for speed. However, often it really isn't necessary and aiming for between 4 and 20MHz will suffice. I would recommend sticking to below 10MHz when breadboarding – above these frequencies we're increasingly likely to run into difficulties with electrical noise due to electromagnetic interference (EMI). This can be a nightmare without a properly laid out PCB. Also, it's nice to have a 32kHz clock (32.768kHz to be precise), which can easily accommodate a real-time clock (RTC) for accurate time keeping.

Debugging capabilities

In an ideal world, we would never need to debug our code because our software is perfectly written and the hardware would always do as it's told. This is rarely the case. It's always useful to make sure there are sufficient debugging capabilities. Usually, an ICSP (in-circuit serial programmer), like PICKIT3 or ICD3 is sufficient for our debug needs. However, we don't want or need to use them all the time, so we can add our own small debug capabilities. This could be as simple as adding an LED to indicate the board is powered or when an event in our code has occurred. My favourite technique is using a universal asynchronous receiver/transmitter (UART) port. Often referred to as the serial port, we could connect up our PC or laptop to this port using a USB-to-TTL serial cable and output strings of useful debug information from our device.

Communication, analogue and digital peripherals

These functions are the main features of any microcontroller. They are what allow us to do all sorts of interesting things using built-in, internal programmable modules. Digital communication blocks include: UART, USART, I2C, SPI, CAN, Ethernet and USB. Useful analogue and digital peripherals include: comparators, converters, timers, external interrupts, analogue-to-digital converters

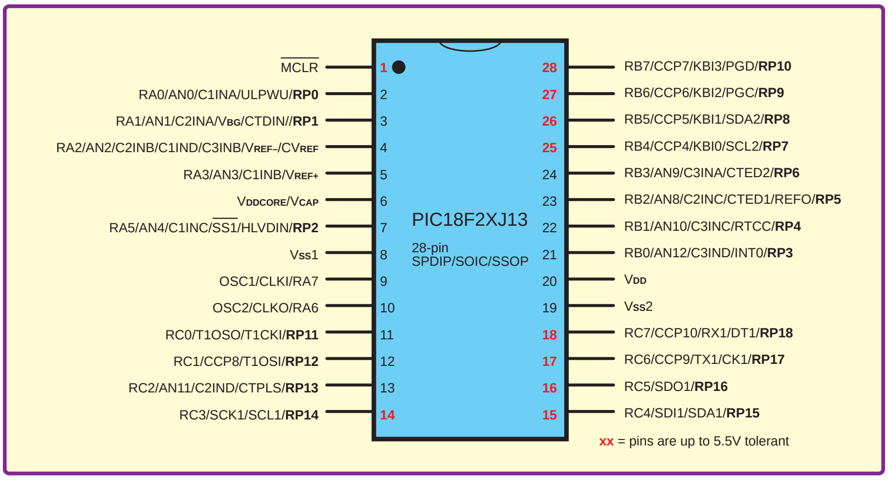


Fig.2. PIC18F27J13 device pinout

(ADC), digital-to-analogue converters (DAC), pulse-width modulation drivers (PWM), parallel master port (PMP – used for driving TFT LED screens) and many many more.

Timers

These are some of the handiest parts of the PIC. There are numerous 8-bit, 16-bit and 32-bit timers available throughout the PIC range. They let us count external interrupts, events, pulses, samples and other timing events.

Example PIC selection

The easiest way to show how it's done is to give an example. Let's have a look at a very simple project – a basic thermometer. LEDs are aligned vertically and light up from bottom to top as a function of a given temperature over a range of 0 to 30ºC. So, with five LEDs, we're looking at about 6ºC for each illuminated LED. We could dim each LED in that range to get better temperature resolution:

1) Five dimmable LEDs
2) One analogue temperature sensor (like the LM335Z/NOPB from Texas Instruments)
3) One UART debug port (it's always good to have a debug port in reserve)
4) One reset button; you never know what will happen!

We now have a rough idea of what we want our PIC to do, so let's look at what our simple specification items will need. LEDs would normally just need a GPIO, but we want dimmable LEDs, this means we'll need four PWM modules – one for each LED. We want to use an analogue temperature sensor, so this means we need an ADC input. We could use an I2C temperature sensor, but an analogue one is easier to work with. Our UART debug port will allow us to hook up our PIC to a PC or laptop using a TTL cable. We could use this port to output the exact temperature value or other debug information if we want. For this, we'll need a single UART module on the board. When using any communication bus, it is always a good idea to use an external clock. For the reset pin, we can either connect a button to our reset pin on the PIC or we could connect it up to an I/O pin and program it using an interrupt in our software.

So, let's pick our PIC. Using the options in MAPS, we select: 8-bit, current products, one ADC module, one UART channel, five PWM channels and let's tick the ICSP button at the bottom of the page. This narrows our selection down to 32 devices. Ideally, we'd like to narrow this down to less than five so we can select a part that is available. We find most of the results come in 64-pin to 100-pin TQFP packages, which is completely over the top for such a small circuit. Selecting these package sizes are non-trivial for the projects we focus on. Even if we had our own PCB, soldering them down is quite an art with a pin pitch as small as 1mm. I would prefer to pick something I can drop into a breadboard or even a socket. The PIC18F27J13 and PIC18F47J13 are available in 28-pin SPDIP packages and are easy enough to obtain. Unfortunately, there doesn't seem to be a parameter for selecting package sizes in the tool, which would make our lives that little bit easier.

Check list

The PIC18F27F13 is a commonly used PIC and very useful. Coincidentally, it's the same PIC used on the *LPLC – Low Power, Low Cost PIC18 Development Board* – by my predecessor, Mike Hibbett. Let's check to make sure we've got the right device and we can do all that we want with it. I've found a few times, that the PIC I'm presented with has all the modules I like, but they're all sharing the same I/O pins, which is not what I want at all. So let's verify this is the right PIC for us. Breaking it down to the functions we mentioned above, we get the following pinout list:

1) The five dimmable LEDs can be driven off the CCP ports (Capture\Compare\PWM) RP12, RP17, RP18, RP7, RP8
2) Our analogue temperature sensor needs an ADC port – RP0 can take care of that
3) Our debug UART ports can only be used by RP18, RP17
4) Our reset button connects to $\overline{\text{MCLR}}$ on pin 1
5) Our external oscillator can be connected to OSC1 and OSC2 on pins 9 and 10
6) Our Programming pins are RP9 and RP10.

Anyone spot the problem here? The debug UART ports and the PWM ports both use RP18 and RP17. So we need to swap those PWM pins to RP9 and RP10 instead, as these are the only other CCP pins that can be used. Now the PWM pins are sharing the same pins as the programming interface. This is only a problem if we want to debug and step through our code because our two LEDs on RP9 and RP10 will not behave as we expect during this mode of operation. Once we've programmed our design, there's no more need for the programming interface and those pins can behave as they need. This is a nice example of the use of the UART as a *secondary* debug output.

We've had a look at a useful example of choosing a PIC for a relatively simple design. Selecting the right part can get a lot more complicated, but once we've made sure we've got the right number of I/O pins, the internal stuff is just ticking boxes.

PIC tips

If I were to choose a PIC from each category then I would choose the PIC18F27J13 as an 8-bit device (128KB program memory) for everyday projects. Next, the PIC24FV16KM202 for 16-bit projects – it has 16KB of program memory, 512KB EE for data, and uses 5V for electrical immunity. Last, the 32-bit PIC32MX695F512H comes with 512KB program memory, Ethernet, USB, CAN and a graphics interface. The PIC32MX part is the only one of these I couldn't easily prototype without making my own PCB. I've worked with each of these in the past and I may use them again in future projects.

Next month

The Christmas season is almost upon us and I think it is only right and fair I make a little PICmas tree. I'm hoping to make it challenging to build in both physical soldering skill as well as software imagination, as well as looking good. Tune in for next month's article for a novel design full of festive spirit.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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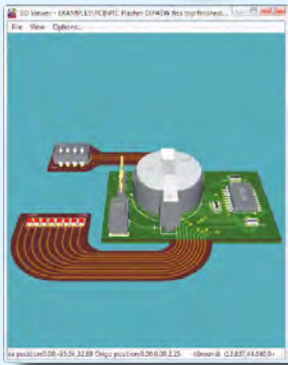

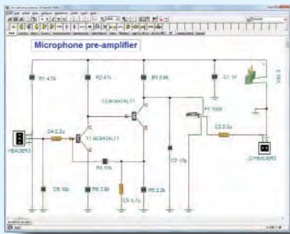

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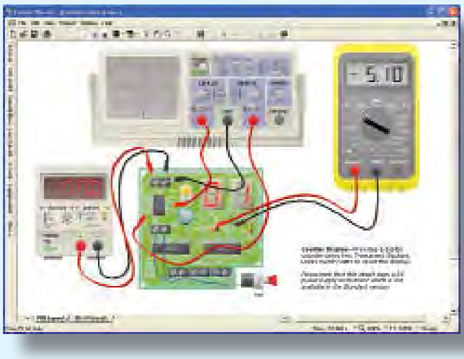

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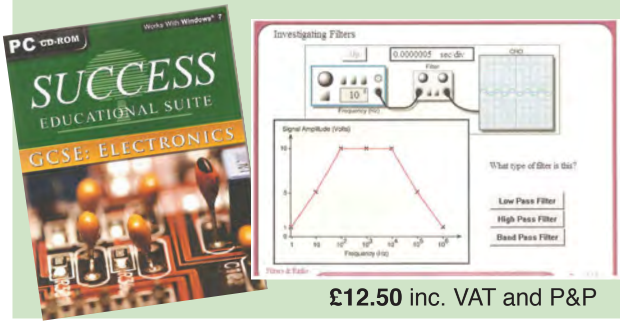

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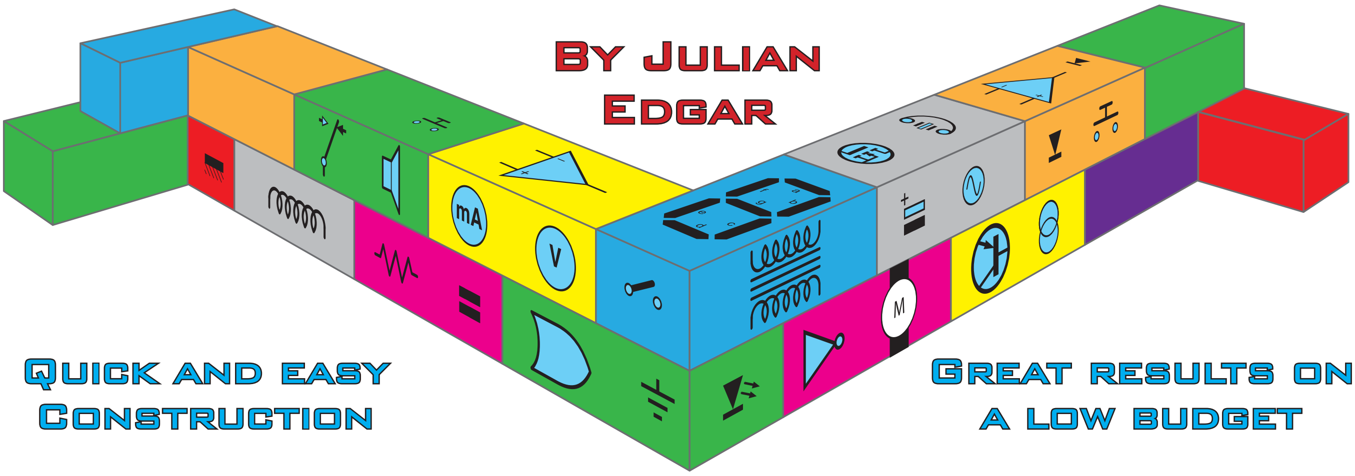
Electronic Building Blocks

By Julian Edgar



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Voltage Booster

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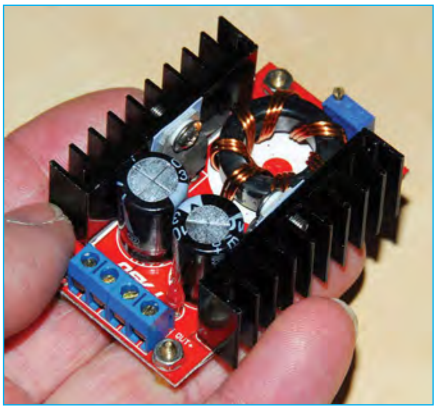


Fig.1. Fantastic value – a flexible Voltage Booster to increase the output of pumps, lights, fans...

Voltage Booster

Here is an incredibly cheap *Voltage Booster* that will help you increase the output of pumps, lights, fans and a whole host of other applications. It costs just £3 to £4, including delivery to your UK letterbox. This handy little circuit has an adjustable voltage output of 12–35V. The power rating is a very impressive 150W (with added fan cooling) or 100W without fan cooling (but to be honest, I would beef up the heat sinks). On the basis of my testing, I'd be happy to run it at 50W to 60W continuous rating without cooling... just as it comes out of the box, as shown in Fig.1.

Construction and use

The *Voltage Booster* module is delivered as an assembled circuit board. It's about 65 × 50 × 30mm (L × W × H), has a heat sink along each long side, a four-terminal connection strip (Fig.2) at one end and a multi-turn pot at the other end. It's well made – in fact, a real quality item, with clear connection markings (in English), good PCB design and four tapped metal spacers (on which it sits).

The unit's connections are simple: 'IN' positive and negative, and 'OUT' positive and negative (Fig.3). (Don't get these connections the wrong way

Fig.2. The Voltage Booster's power in/power out terminals

around, and do make sure you don't short-circuit the output.) Before powering-up, turn the pot many turns anti-clockwise to reduce the gain; then turn it clockwise to slowly bring the circuit up to the target output voltage – see Fig.3, and note that this diagram is the view from above. A multimeter is the easiest route to measuring the output voltage

An example wiring installation running a pump is shown in Fig.4. When the wiring is complete, the board should be mounted in a ventilated box.

Efficiency?

So how efficient is the module? Efficiency is important for two reasons.

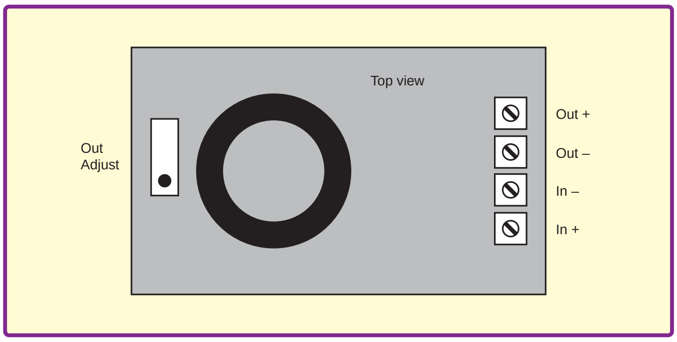


Fig.3. Voltage Booster connections (top view)

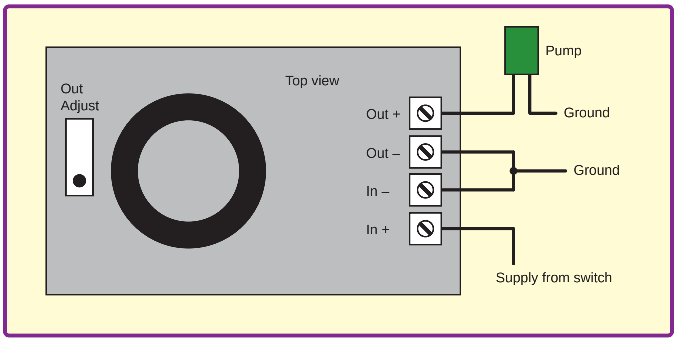


Fig.4. Voltage Booster pump application

First, the less efficient it is, the more heat it will have to dissipate. Second, the less efficient it is, the more energy it wastes – and if you're running say a camping lighting system from a battery, you don't want to waste much energy.

The manufacturer claims an efficiency of 94% when running with an input voltage of 19V, a 2.5A current draw, and an output of 16V. However, that's not normally how you'd use it. In my testing, with an input voltage of 12.0V, an output of 14.7V and a current draw of 1.25A, the efficiency was 91%. In other words, the power consumed was 15.0W and the output power was 13.7W – an internal loss of 1.3W. That's still pretty good.

Conclusion

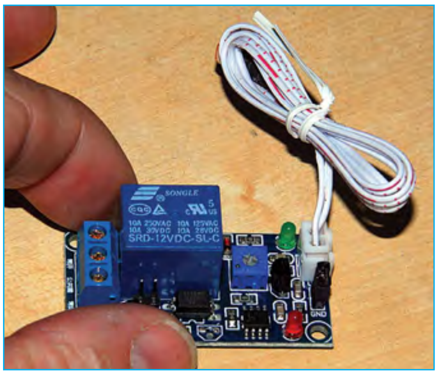
You can use this *Voltage Booster* for battery charging from a lower voltage supply, to make up for voltage drops in long wiring, or to simply brighten low-voltage filament lights – cheap, simple and effective.

Sourcing

To find this handy little unit, do an eBay search under '150W DC-DC 10-32V to 12-35V Power Supply Module'. At the time of writing, a typical example is eBay item 151802710882 for the remarkably cheap price of £2.69, plus £1 delivery.

Next month

Here is an incredibly cheap *Voltage Switch* (just £5 including delivery to your UK letterbox) that activates a relay when the input voltage reaches the required level. Don't miss our next *Electronic Building Blocks* article!



Next month – a Voltage Switch

PCB SERVICE

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Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

PROJECT TITLE	ORDER CODE	COST
SEPT '14		
Build An AM Radio	06101121	£9.10
LED Ladybird	08103131	£6.94
Lifesaver For Lithium or SLA Batteries	11108131	£5.32
Do Not Disturb Phone Timer	12104131	£9.10
OCT '14		
SiDRADIO – Main PCB	06109131	£24.75
– Front & Rear Panel Set	06109132 } 06109133 }	£19.35
Hi-Fi Stereo Headphone Amplifier – Part 1	01309111	£16.65
NOV '14		
GPS Tracker	05112131	£13.15
DEC '14		
PortaPAL-D – Main PCB	01111131 }	
– Microphone Input	01111132 }	£33.94
– Guitar Input	01111133 }	
Electronic Bellbird	08112131	£11.53
JAN '15		
"Tiny Tim" Stereo Amplifier	01309111	£16.65
– Power supply	18110131	£11.80
FEB '15		
Audio Delay For PA Systems	01110131	£13.42
Teach-In 2015 – Part 1 Pre-Amp	905	£9.33
MARCH '15		
Stereo Echo & Reverb Unit	01110131	£13.42
Super Smooth, Full-range, 10A/230V Speed Controller for Universal Motors	10102141	£11.80
APRIL '15		
A Rubidium Frequency Standard For A Song	04105141	£8.02
USB/RS-232C Interface	07103141	£7.48
Teach-In 2015 – Part 3	906	£8.75
MAY '15		
Deluxe Fan Speed Controller	10104141	£10.72
RGB LED Strip Driver	16105141	£8.56
Low-cost Precision 10V DC Reference For Checking DMMs	04104141	£7.48
JUNE '15		
Burp Charge Your Batteries	14103141	£13.40
Teach-In 2015 – Part 5	907	£8.55
JULY '15		
L-o-o-o-n-g Gating Times For The 12-Digit High-Resolution Counter	04106141	£11.55
Threshold Voltage Switch	99106141	£10.15
Touch-Screen Digital Audio Recorder – Part 2	01105141	£13.70
AUG '15		
Nirvana Valve Simulator – Main PCB	01106141	£15.05
– Front Panel	01106142	£8.30
TempMasterMK3	21108141	£12.00
Teach-In 2015 – Part 7	908	£8.75

PROJECT TITLE	ORDER CODE	COST
SEPT '15		
Opto-Theremin – Part 1		
– Main Theremin	23108141	£14.25
– Volume Control Board	23108142	£6.95
Mini-D Stereo 10W/Channel Class-D Audio Amplifier	01110141	£7.45
Wideband, Active Differential Oscilloscope Probe		
– Main PCB	04107141 }	£11.80
– Screening PCB	04107142 }	
OCT '15		
Digital Effects Processor For Guitars And Musical Instruments	01110131	£16.40
Courtesy LED Lights Delay For Cars	05109141	£8.55
Teach-In 2015 – Part 9	909	£10.70
NOV '15		
The Currawong – Part 1		
– Main Board	01111141	£47.20
– Front Panel	01111142 }	£24.75
– Rear Panel	01111143 }	
48V Dual Phantom Power Supply	18112141	£9.37
Programmable Mains Timer With Remote Switching		
– Main Board	19112141	£11.80
– Front Panel	19112142	£16.40
DEC '15		
TDR Dongle For Oscilloscopes	04112141	£7.20
High-Energy Multi-Spark CDI For Performance Cars	05112141	£11.80

*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at: **www.epemag.com**

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

EPE PRINTED CIRCUIT BOARD SERVICE

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http://www.epemag.com

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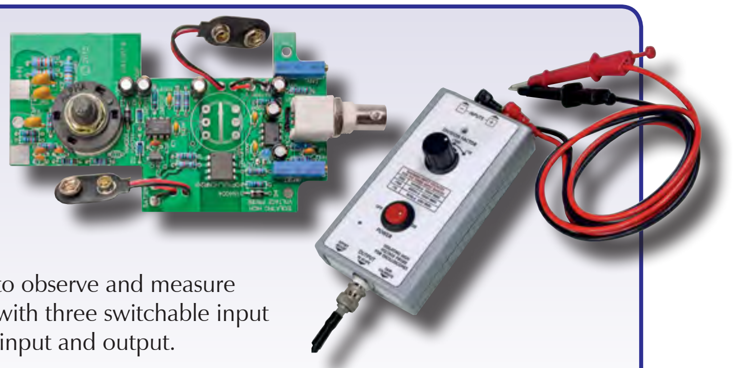
Next Month

Content may be subject to change



Isolating High Voltage Probe for Oscilloscopes

Fancy a low-cost project which allows you to use your oscilloscope to observe and measure AC mains and other high voltage waveforms safely? Well, here it is, with three switchable input voltage ranges, wide bandwidth and high voltage isolation between input and output.

High-Energy Multi-Spark CDI for Performance Cars – Part 2

In Part 1, we introduced our new exciting *High-Energy Multi-Spark CDI* and described its operation. Next, we give the assembly details for six different versions to suit your car's trigger source, and describe the installation.

The Currawong Stereo 10W Valve Amplifier – Part 3

In the first two instalments of our fantastic *Currawong Stereo 10W Valve Amplifier* we described its circuit and gave the PCB assembly and wiring details. This final article describes the optional remote volume control, the all-important transparent safety cover and the setting-up procedure.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work*.

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